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HAPTICS: FOR A MORE EXPERIENTIAL QUALITY IN A COMPUTER INTERFACE.

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ABSTRACT:

Applied artists and product designers encounter difficulties in adapting to digital tools which could theoretically improve their practice. The Tacitus project has adopted user-centered methodologies to investigate the potential advantage offered by digital media, particularly during the germinal phase of the design process, by developing a novel interface which exploits spatial input, haptic force-feedback and stereovision.

This paper presents theoretical implications and experimental results obtained from the first studies of an early prototype for sketching in three dimensions, with the focus on qualitative evaluation. The underlying principle of the 3D sketching 'widget' is to support designers by merging those qualities typically offered by sketching and modeling with advantages of digital interfaces.

The first part of the paper presents a review of guidelines extracted from research within the Design and the Scientific Community. The second part describes the prototype, with qualitative evaluation of its advantages and drawbacks, in terms of usability and perceived workload, for feed back into iterative development.

KEY WORDS: haptics, 3-dimensions, designers, applied artists, experiential, germinal phase, creative process, interface, conceptual.

1.1 INTRODUCTION

The potential advantage offered by digital media, particularly during the germinal phase, is squandered due to the load imposed on the cognitive process of applied artists and designers by the existing digital interface. Literature shows that traditional media such as sketching and three-dimensional modeling are preferred during early conceptualization, even in practices dependent on digital processes at later stages. A survey conducted among practicing product and engineering designers in 2001 revealed that in 93% of cases a computer-based output was required from the design department, but a large amount of projects (73%) would include sketching or rough physical models in their early phase. (Wiegers and Vergeest, 2001)

Previous research conducted within the Tacitus Project (Scali, Shillito, Wright, 2002) focused on the role of sketching and particularly on physical modeling. The study suggests that rough physical models serve a specific purpose, as they might support spatial reasoning by 'existing' in space. If particular qualities from traditional media and practice could be embedded in a digital environment, a more qualitative experience of designing with computers would benefit thedesigner's cognitive needs and respond to industries' requirements more effectively.

A set of specifications were extracted for the optimal hypothesized tool to support the germinal phase of designing in three-dimensions. The findings and specifications from the above paper will be summarized in the following paragraphs, as they distil the theoretical positions which originated the novel sketching system evaluated in this paper.

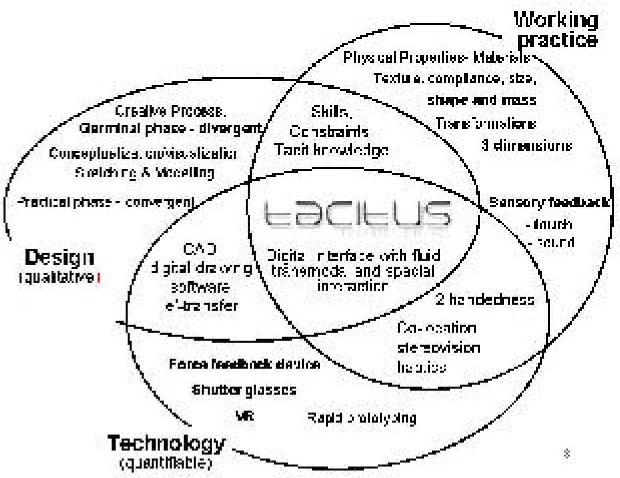


Figure 1: The three domains that inform the Tacitus Project: working practice, design and technology.

1.2 INDUSTRY REQUIREMENT, DESIGNERS NEEDS

In industry the design and manufacture of products has rapidly shifted towards the use of computers for almost every stage, imposing a conflict between computing and traditional design practice. Highly digitized industrial processes tend to overlook the role of the designer in the process itself. (Scali, Shillito & Wright, 2002)

Current computer-based tools tend to stifle rather than support the creativity of users: The counterintuitive interfaces of computer aided design (CAD) software and the lack of spontaneity afforded by the modeling methods can prove disruptive. (Chesire, Evans & Dean, 2001)

There is an increasing awareness that 'the efficiency and the quality of future product developments depend upon the gap being closed between quickly developing technologies and cognitive abilities and limitations of the designer.' (Romer, Pache, Weißhahn, Lindemann & Hacker. 2001 pg 474). This statement particularly applies to the germinal phase where the generation of ideas is central.

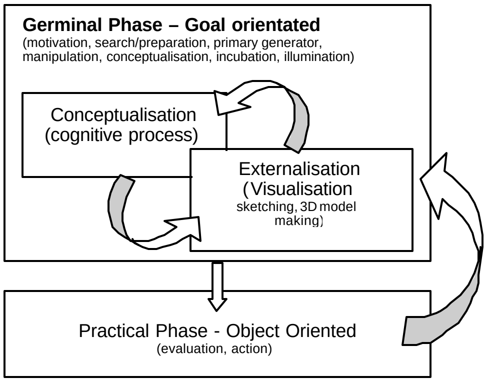


Figure 2. Creative process from germinal to practical phase.

Sener et al. note that introducing a digital tool as early as possible in the design process seems to be desirable (Sener, Joris, Vergeest and Akar, 2002) both for designers and for the subsequent production stage. Conversion to a digital form is almost mandatory at later phase, therefore the process would be improved if there was better integration from the early design phase to its end. As for designers, they could certainly benefit if the conceptual design stage was enhanced through the development of suitable computer tools. (Sener et al, 2002). This would be an advantage for all designers and for industry, since 'decisions made in conceptual design have a very large impact on the overall product success'. (Sener et al, 2002: pg 540). Those observations are supported by results of a survey investigating CAD requirements which ranked a tool for computer-based, early evaluation and analysis of design alternatives as a top priority. (Wiegers, & Vergeest, 2001)

1.3 CONCEPTUALIZING: SKETCHING AND MODELING

A literature review (Scali et al, 2002) investigated the reasons behind the continued use of traditional media during conceptualization despite the advantages brought by digitalization. Since non-digital tools are so popular during early phases of design, it could be argued that 'crucial aspects from non-digital tools should be integrated into future computer-based Tools'. (Romer et al, 2001 pg. 474)

Physical models in particular might support spatial reasoning for they 'exist' in space. It seems that their inherent 3D structure allows an experience of that space not only through vision but also, it has emerged, through manipulation and haptic (touch) interaction.

As far as three-dimensional reasoning is concerned, research in psychology (Parsons, L 1995) and in Human Computer Interface (HCI) shows that ' experiencing' 3D space helps the user to understand it (Zhai and Milgram 1998). The 'tangibility'of the hardware, and the possibility for it to be appreciated by at least two senses is relevant to the design process. Brereton and McGarry, 2002)

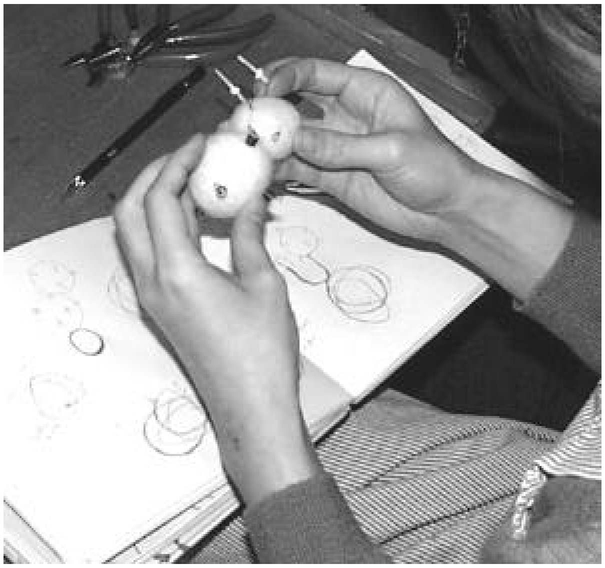


Figure 3: Design conceptualization process – jeweller physically exploring form relationships.

The importance of manipulo-spatial activity, that is, the combination of mental and motor processes, has been recognized in research on industrial design. (Tovey, 1986)

In this context, the use of two hands has emerged as significant, as the modality of two-handed exploration seems relevant for shape perception. Physical interaction with objects often happens with both hands in daily actions.

This observation is supported in Guiard's psychological analysis of human skilled two-handed action in right-handed subjects. His kinematic chain theory could be applied to the making activities of designers. The theory suggests the co-operation of two hands in defining a spatial 'frame' for actions, and also the correlation between using both hands and increasing performance in skilled action. (Guiard, 1987)

The characterization of the designer as 'thinking with their hands' while creating or manipulating physical models echoes the sentiment of Schön when he described the act of freehand drawing as a conversation with the image. (Schön 1983)

Investigations such as a multi-year study on engineering design students and professionals show that physical objects play a relevant role during concept design, as designers appear 'active and opportunistic in seeking out physical props to help them think through design problems and communicate ideas' (Brereton, & McGarry 2000 pg 223). It is argued that design is heavily dependent upon references to physical objects and gesturing with physical objects.

1.4 TOOL SPECIFICATIONS

From the above analysis, Scali et al. proposed the following specifications for a tool which helps thinking in the three-dimensions.

a. Such a tool should respond to a specific cognitive need of the designer, that is, 'thinking in space' effectively. As extracted from literature and presented in the review by Scali et al (2002) that experience might be enhanced by multi-sensory appreciation and by a 'tangible' experience of three-dimensional space. Vision, manipulo-spatial and gestural activities (particularly involving two hands) seem to increase information gained about an object in space. Hence, a first general set of tool requirements could be summarized as follows:

The tool is "tangible" in space as it allows perceptual 'experience' of space; affords multi-sensory appreciation, manipulation / gestures, and bi-manual interaction.

b. Available digital tools often lack support for divergent activities typical of the germinal phase, such as quick generation and evaluation of alternatives.

Although rough models provide the multi-layered information about three-dimensional design problems, they are relatively costly and time-consuming, and therefore used more sporadically than sketching. Sketching offers ease of use, unencumbered / fast access and quick production of results, as proposed by an earlier Tacitus paper (Shillito, Paynter, Wright, Wall, 2001), and it is the most popular support for divergent activities.

An additional quality offered by sketching and models is immediate and continuous feedback for evaluation (e.g. manipulating physical models), and is preferred to accuracy at this stage, as fluency supports the streams of thought typical of the creative process. Therefore, requirements related to the designer's need in the germinal phase can be summarized as follows:

The tool supports divergent and convergent activities in the germinal phase by providing real-time feedback (no snap-shots, no interruptions); flexibility affording easy changes; ease of use, accessibility (no-steep learning curve); fast results, (immediacy over accuracy).

Figure 4. Divergent, convergent and iterative activities in designing: models by Edinburgh College of Art Architecture students.

c. The hypothesized tool should meet industry‘s requirements in order to be usable in standard design practice. Improved integration of the conceptual phase, typically non-digital, with subsequent digital phases of the process could bring cost benefits in this area. The provision of good tools for conceptualization would benefit designers, therefore improving overall quality and indirectly reducing costs further. Tool specifications for use in Industry can be described as follows:

The tool meets Industry requirements as it is cost effective; integrates with existing digital industrial processes and reduces process time.

The hypothesized tool could be described as a process catalyst (Scali et al. 2002) since its main functions are to ease and enhance;

- the designer’s cognitive activity and mental processes (continuous feedback, unencumbered interaction),
- the practical process of designing (easy interaction and fast results),
- the overall design process (improving costs and time efficiency, as well as results).

2. SYSTEM IMPLEMENTATION

2.1 VIRTUAL ENVIRONMENTS, CO-LOCATED DISPLAYS AND HAPTIC TECHNOLOGY: TECHNICAL REQUIREMENTS.

Although Virtual Environments are regarded as the most ‘natural’ environment for spatial interaction, practical implementation presents many drawbacks. Difficulties, such as disorientation, arise from the lack of constrains and limitations for precise input and control. This is mainly due to the lack of spatial ‘reference frames’, i.e. the grounding and support that humans find in everyday life in the physical environment of objects and materials.

Spatial interfaces can use the physical constraints offered by objects to support exploration in virtual space. Examples of physical devices tracked for virtual display include ‘digital clay’ and ‘shapetape’. These types of constraints can reduce cognitive load as users can try configurations of objects by moving their hands until they hit something. However physical props can in turn limit the flexibility offered by a digital medium.

Therefore software constraints could be

preferable even though a small cognitive load may be impose by the limitations of software constraints and their feedback that users must comprehend.
(Hinkley, Pausch, Gobel & Kassell, 1994).

Figure 5. Digital clay: individual modules able to sense others in an assembly

A valuable compromise between physical constraints and digital systems could be provided by Haptic displays and force feedback devices as these are ‘programmable’ and will to a degree allow the transfer of everyday skills for manipulating tools. A force feedback device such as the Phantom provides rotation through six degrees of freedom (DOF) which is necessary for operating freely in three-dimensional space.

Figure 6: Phanton force feedback device with six degrees of freedom.

Haptic constraints, as programmed ‘widgets’, should ideally be built around user requirements and tasks. For the designer wishing to explore ideas and creative solutions in a fast and intuitive manner. this fluency needs to be achieved in a 3D virtual environment. For this reason it is necessary to address issues such as comprehension, target acquisition and trajectory-following in 3D space.

Consequently the main motivation of an early investigation into the use of virtual magnets (or gravity wells), (Wall, Paynter, Shillito, Wright and Scali, 2002), was to objectively assess their capacity to improve precision in a targeting tasks. Results suggested that haptic force cues via virtual magnets can help users to improve their accuracy. This result is strengthened by other findings and one by Bouguila et al. (2000), which suggest that haptic feedback can help to overcome instabilities in subject’s depth perception.

Force feedback devices integrated with co-located displays, offer an interaction space coherent with the user's spatial awareness. Research shows that co-located displays improve performance under certain conditions, notably when 3D rotation is involved. (Ware and Rose, 1999)

Co-located displays and stereo glasses are often employed simultaneously to provide 3D-depth information and simulating true stereo vision of 3D objects.

Figure 7. Reachin System: space co-located with force feedback device.

Figure 8. Reachin System: space co-located with device and stereo glasses for 3D vision.

The hypothesis is that spatial interaction, haptics and stereovision, together with co-location, provide a viable hardware specification to integrate the third dimension into a novel digital modeling system.

At present such a hardware configuration does not comply with the low-cost requirements of designers and industry. Substantial investment could be justified in large design firms but haptic displays will eventually be mass-produced with comparable, cheaper systems.

The system under development is at concept stage for future commercial implementation. It uses a Reachin Developer Display calibrated with a PHANToM haptic force feedback device and instrumented stylus operated with the dominant hand. A Magellan 3D spacemouse provides input using the non-dominant hand.

2.2 IMPLEMENTED SOFTWARE: 3D SKETCHING IN SPACE

The specifications discussed above were used to devise a 3D sketching programme, one part of a conceptual modelling development which will include "modes" for surface and primitive solids creation.

Users wear stereo glasses and look into the co-located display where they are able to act within the workspace via the stylus of a Phantom Force Feedback Device, providing 6DOF spatial input and programmed force feedback as described in paragraph 2.1.

The avatar of the Phantom stylus is seen as a ‘drawing tool’. Its main function in this programme is to allow the user to draw lines and sketch in three dimensions. The result is a hybrid between a sketch and a model form ‘fabricated in wire’.

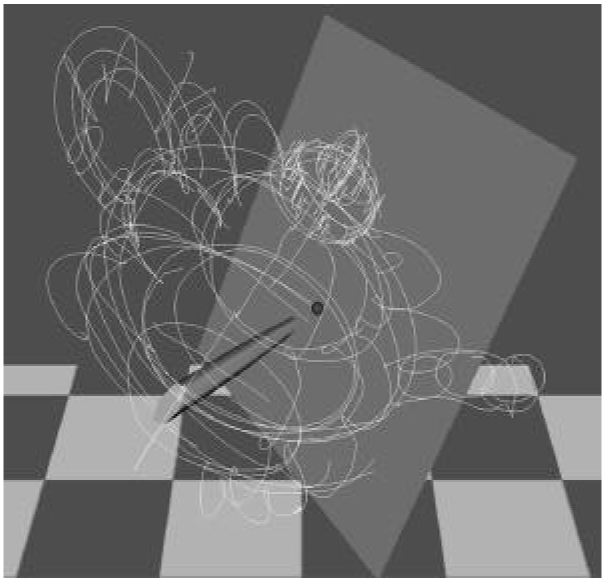


Figure 9. 3D space showing haptic plane, avatar of stylus for force feedback, floor of workspace and sketch of teapot.

Haptic ‘widgets’, as a spring force to simulate a weak magnetic force and tested in previous research, are employed to help the user target lines or the end of lines more precisely while drawing.

An additional ‘widget’, a haptic plane, provides a spatial constraint that can be switched on and off by clicking a button on the spacemouse. Once brought into play, the plane appears perpendicular to the tip of the stylus, and can be rotated freely. Once it is in a desired position and the button released, the plane can be used to draw on in a more constrained mode.

The floor of the workspace is delineated by a checkerboard patterned surface and is the only space boundary constraint implemented in time for the experiment.

A Magellan space mouse provides buttons as shortcuts for the software, and controlled rotation of the sketched shape. The heavy space mouse sits in a static location on the user's desk and this potentially limits the benefits possible through bi-manual interaction. This is an issue that should be addressed with additional research.

3. EXPERIMENT

The aim of a small field trial was to gather qualitative feedback using domain experts and validate specifications drawn from searches and informal personal experiences, as the first step in an iterative context-based study. The perceptions and experiences of this small group, using ‘haptic widgets’ implemented in the 3D sketching application as described above, was collected using questionnaires at the completion of each ‘condition’.

Results of analysis will be used to refine the 3D sketch software and inform the next stages in an iterative cycle. Results will also provide the framework for subsequent development of ‘solids’ and ‘surface’ prototypes, to reflect the context in which the system will be used.

3.1 HYPOTHESIS

The study aims to assess the subjects' perception of three prototype systems. Due to the qualitative nature of the study and the low number of participants, the evaluation of the designers’ perceptions of the tasks is focused on feedback and comments obtained in a questionnaire, as these subjects represent the target user group of the final application. Additional data to evaluate the system’s usability was gathered using a rated user system, a SUS (System Usability Scale -Brooke 1996), and a computer version of the NASA-TLX (Task Load Index- Hart and Staveland 1988) test. Data from the latter is to be compared with workload scores to be obtained in later investigations, and results are not discussed in this paper due to the low number of participants; data gathered from those tests will be used to plan further investigations.

3.2 EXPERIMENTAL DESIGN AND PROCEDURE:

The four people selected for the experiment come from media design, product design, ceramics and sculpture and use CAD and graphic software in their practice.

Each user was given time to become familiar with the system, and then asked to perform two sketching tasks, under three different conditions, each selected at random.

Each condition tested variations of haptic ‘widgets’. Otherwise the systems (described in paragraph 2.2) were the same as all included the haptic plane. This ‘plane’ widget and its interaction and use with the different line ‘modes’ was evaluated across systems. As the line ‘modes’ will be integrated as a unique tool at a later stage, this experiment constitutes a preliminary evaluation of their separate advantages and disadvantages in order to achieve the best amalgamation possible.

The first drawing tool for testing has haptic ‘magnets’ attached to the ends of each ‘drawn’ line. This tool should provide support in locating more easily the start and end points of lines.

The second drawing tool produces a line with ‘magnets’ scattered along its length. Magnets are dropped according to the drawing speed, i.e. a slower speed produces an increased concentration of magnets. This mode might be useful when extra support and control is needed.

In the third condition a drawing tool produces a non-haptic line, corresponding to sketching freely in space when no haptic constraints are desired. It should therefore be the easiest and quickest tool, although lack of constraints can be perceived as a shortcoming.

Users were each allotted four hours to carry out the following tasks: get accustomed to the system, then draw a given object (the same for all the users), and sketch a mental image/form of their own choice under the three conditions.

Figure 10. Perfume bottle: the given object to sketch.

At the end of each ‘condition’ subjects were required to complete two evaluations of the systems (SUS and tlx), fill in a questionnaire on the separate elements of the interface, and score their performance.

Evaluation consisted of open and rated questions about the system and its individual elements. The open questions were to specifically stimulate positive and negative comments as well as illicit suggestions for improvements and possible solutions to perceived shortcomings.

The conditions were performed in random order to minimize the risk of a learning transfer effect and/or a higher perception of the total workload due to tiredness.
A camcorder was used to record a small section of the experimental sessions to collect visual and verbal commentary on the experiment.

4.Discussion

Feedback from the designers was useful and overall confirmed the expected outcome. Various comments were consistent across all the users, and thoughts for future improvements as well as perceived limitations of the system were collated.

4.1 General comments on the system

Many of general comments about the prototypes, across conditions, seem to support the theoretical framework discussed above.

Two of the subjects explicitly rated the ability to rotate the sketch in space among the positive qualities of the system, and correlated three-dimensional rotation with a better perception of the three-dimensionality of the system.
These comments seems to be in agreement with the general assumption that the system could provide a suitable environment for working in three-dimensional space, and provide an ‘experiential’ quality to the perception of shapes in space.

The system was also generally described as being ‘easy’ to use and ‘intuitive’; one user commented that working with the system was ‘very absorbing’. This could illustrate the fact that the system somehow draws on acquired skills for dealing with space.

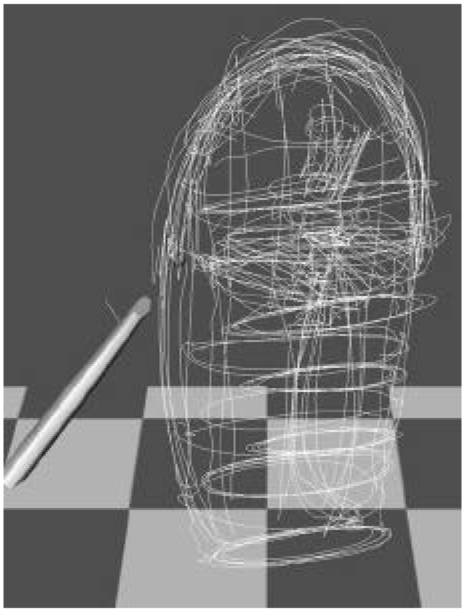


Figure 11. 3D Sketch of perfume bottle with haptic magnets on ends of lines (met).

Specific comments highlighted drawing speed and quick results, with ‘virtually no need for training’, as additional positive qualities. This seems to comply with specifications for an interface which embeds the immediacy of physicality in a modeling system.

Negative comments highlighted shortcomings of the system, and related to the hardware and to interface features.

Many of the problems reported in the questionnaire refer to well-known VR issues and will not be elaborated on further in this paper as they address areas outwith its scope. They must, though, be taken into account. Some users were disturbed by the flickering and heaviness of stereo-glasses. Others noted a perspective distortion due to the fact that the movements of the head were not tracked.

Other hardware-related problems were specifically about the Reachin system and the input device; for instance, time lags were experienced, as information could not always be processed smoothly in real-time, with visual output inconsistent with user input.

Three of the users commented on the physical limitations of the drawing space as they felt constrained by the physical boundaries of the workspace. One stated that they ‘sometimes hit the edges of the drawing space and was not able to draw lines unless the object was rotated’. This consideration could be attributed to the fact that as the workspace boundaries are not visually indicated, users ‘expected’ unlimited freedom whereas the device does not provide it.

One user wanted the Phantom's arm to tilt further in space. Even with 6DOF, the force feedback device has physical restrictions to its flexibility. Calibration problems between the stylus end and the virtual tool occurred sporadically, both generally and within corners of the physical space.
Encountering unwelcomed constraints was perceived to be as undesirable as not having constraints where and when it would have felt ‘natural’ to encounter them. Some comments suggested that basic interface features should be introduced to increase control over the position and orientation of objects in space, i.e. spatial references and grids, rotating and scaling the object, and ‘snap to axis’.

After interaction with the non-haptic line prototype, a user commented on their perceived loss of the ‘expected’ physical quality of interaction. As stated above, this could be due to inconsistency, that visual depth information is not being supported by the physical ‘tangibility’ of the environment. This loss of ‘control’, due to the absence of physical constraints, can theoretically be addressed via implementation of appropriate haptic ‘widgets’. In fact, this user commented that ‘the loss of the physical quality’ was partially reconciled by the use of the haptic plane tool.

Additional interface features, such as an ‘erase’ or a ‘duplicate’ tool, were obviously indicated as necessary interface improvements. These comments, more specifically relevant to later stages of the project, were expected as many ‘default’ interface features were specifically excluded from this early prototype.

4.2 Evaluation of haptic interface elements

4.2.1 Haptic plane tool

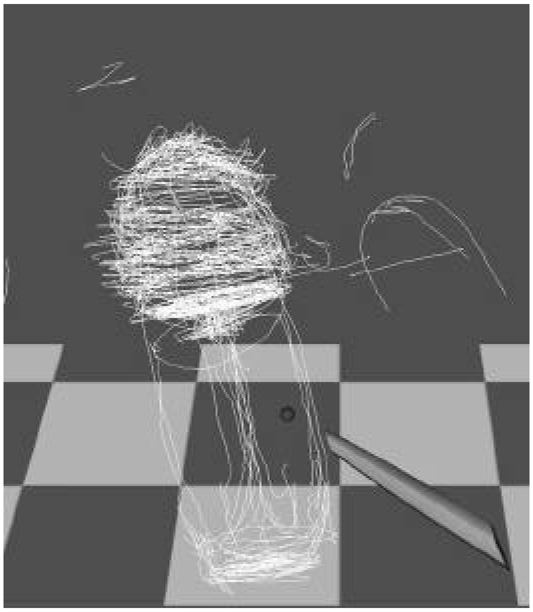
The haptic plane tool, available under each condition, elicited mostly positive comments from users, as the haptics embedded in the plane appear useful for providing a natural and consistent ‘support’ for action (as noted in the previous paragraph). Encouraging answers stated that the plane seemed to help perception of depth in space, although at this stage it is unclear if this was a visual rather than a haptic effect.
Features suggested to improve the plane include being able to rotate the plane, with the object, once it has been positioned; additional visual-haptic features to aid fine control, such as a visual or haptic grid; semi-transparency. The latter seems to be part of a generalized demand for additional visual depth cues, such as the reference given by an object in the background (Hinkley, Pausch, Goble and Kassell 1994).

4.2.2 Line tool

As outlined in previous paragraphs, the three prototype systems presented different line ‘modalities’. The aim of the experiment was to garner users' comments through direct engagement with each widget and their interaction with the system in general. This evaluation will assist their eventual amalgamation into a unique customizable tool.

The non-haptic line was praised for its smoothness, but the same fluidity was also considered to be a negative quality, as users felt it was difficult to ‘control the mark’, and to be precise when required.

Figure 12. 3D Sketch of perfume bottle with no haptic magnets on line (nht).)



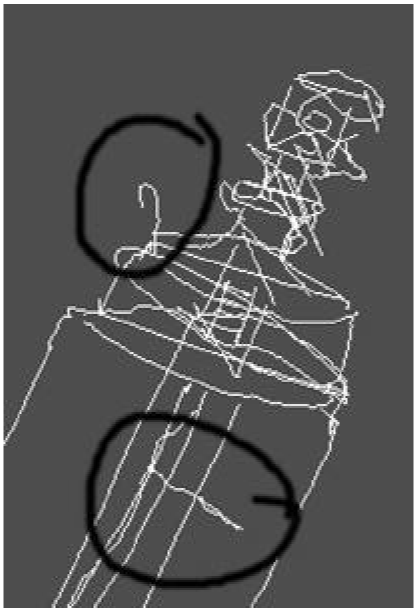
Suggestions were made on how to increase ‘control’ of the line, for instance, by regulating the line's fluidity. This might be achieved by introducing a haptic widget to select the density of the work environment to provide a dampening, more ‘resistive’ media to increase the feeling of control over movements.

This same issue about control arose in the evaluation of the haptic line magnets, implemented and tested under two of the conditions.

Users recognized straight away the role of haptic aids in precision targeting; nevertheless shortcomings were also ascribed to the very same widgets, as their presence seemed to hinder the fluidity of the sketching process.

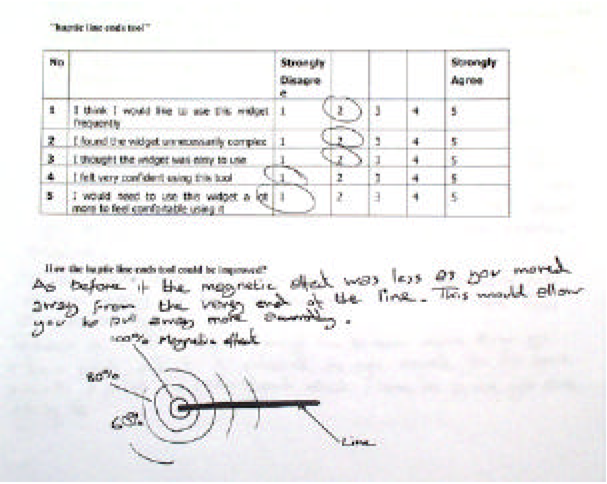
So, among positive comments, users noted that ‘it was easier to locate the ends of the line with the aid of magnets’, and that such a widget ‘has the potential to make computer sketching very accurate’. But the attraction of the magnets was found to be too strong as it forced the user to apply a certain amount of force to release the pen from it. This was judged to be tiring, and was indicated as a source of errors as ‘the drag makes it very difficult to follow the intended path – the magnet unsnaps very quickly and the power put into pulling away is transferred into a line in the wrong direction’.

Figure 13. Detail of sketch of perfume bottle with errors created by pulling hard off magnets on ends of lines (met).)



Haptic magnets were generally rated as potentially useful and some suggestions were made for improvements; for instance, two users envisaged a gradated magnetic well with diminishing hold which would allow the pen to leave the area gradually to achieve a more controllable transition.

Additional proposals were the re-positioning the magnets along the line accordingly to the user's wish, and switching the magnets on and off.



"Haptic line ends tool"

No		Strongly Disagree				Strongly Agree
1	I think I would like to use this widget frequently	1	[✓ 2]	3	4	5
2	I found the widget unnecessarily complex	1	[✓ 2]	3	4	5
3	I thought the widget was easy to use	1	[✓ 2]	3	4	5
4	I felt very confident using this tool	[✓ 1]	2	3	4	5
5	I would need to use the widget a lot more to feel comfortable using it	[✓ 1]	2	3	4	5

How the haptic line ends tool could be improved?

As before if the magnetic effect was less as you moved away from the very end of the line. This would allow you to pull away more smoothly.

Figure 14. Suggestion by participant in 3D sketching study for improving interaction with magnets at ends of line.

Although haptic widgets featured in both line systems, negative comments on the line tool with haptic ends were more frequent, that is, these magnets were more disruptive to action when they were only on the ends of the line. Conversely, magnets scattered all along the line's length made interaction ‘tiring’ and ‘demanding’; nonetheless negative perception seemed to be more dependant on the sudden variation between a haptic and a non haptic state of the line.

As explicitly indicated by one of the users, this might be due to the unexpected physical resistance imposed by the magnets to the hand's movement, followed by complete freedom in the line's middle section once the magnet has ‘let go’. It is probably for a similar reason that the magnetic line-ends were described as ‘not useful’ by one of the subjects and ‘clunky’ by two of them. Yet users also commented positively on the feature, recognizing its effectiveness in targeting the line ends.

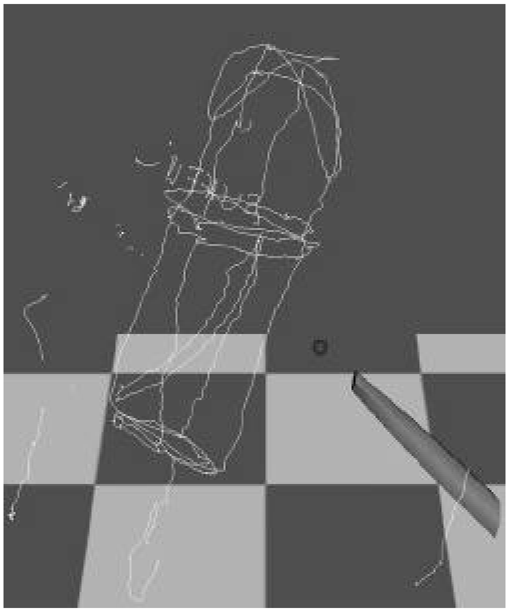


Figure 15. Perfume bottle sketched using tool with magnets scattered along line. (hlt)

This suggests that customizing the use of magnets with ‘ad-hoc’ moveable widgets could address the perceived shortcomings effectively. An additional suggestion was made for indicating the precise location of magnets on the line by means of a distinct change of colour. This comment can be rooted in the broader issue of the need for ‘coherency’ between visual and haptic features of the system, and relates to the previous concern of ‘unexpected’ limitations, due to physical hardware restrictions, in the inadequately demarcated workspace.

Overall results gathered from the SUS (System Usability Scale) appear consistent with that extracted from the questionnaire on widgets. The trial system featuring no haptics along the line has been rated as the most usable by all subjects, although this is not statistically relevant due to the low number of subjects.

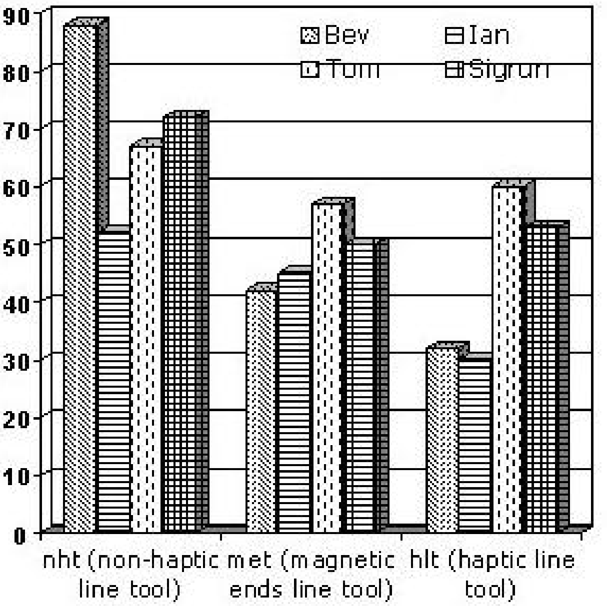


Figure 16. SUS ratings for the 3 experimental conditions – nht, met and hlt.

Relevant suggestions will be used to improve the prototypes for further comparative investigations.

5.Conclusion and future work

The overall results from the study can be judged satisfactory. They have provided valuable information about perceived advantages and shortcomings of the three-dimensional sketching system at this early stage of its development and validated specifications requiring corroboration for future implementation.
Both positive and negative responses seems to suggest that major issues to be addressed are of control and coherence, that is, users need to be able to access different features for different tasks in a coherent environment.

On a practical level, lack of customization seems to provide a sound explanation for the same haptic feature being rated negatively but praised for certain qualities; this is relevant to our investigation as it endorses the envisaged integration of functions in a customizable tool.

On a broader level, Jacob (Jacob, 1992) hypothesized that the structure of the perceptual space of an interaction task, whether two dimensional or three dimensional, should mirror that of the control space of its input device, whether mouse or device with 6DOF, as its effectiveness is relative to the task rather than absolute. This might explain the problem that seems to recur in those occasions where users perceived a mismatch between what they expected and the actual interaction.

In general it seems that haptic widgets could allow the intended action to be performed in a more effortless and easy action where they were coherent, or at least do not clash, with information obtained through vision.
These consideration will be used to improve, develop and merge the 3D sketching prototype with solids and surfaces, through further comparative investigations to provide proof of concept: how haptic input could provide a more experiential quality in a computer interface and influence how the user thinks within a task.

REFERENCES:

Bouguila, L., Ishii, M., Sato, M., ‘Effect of Coupling Haptics and Stereopsis on Depth Perception in Virtual Environment’, *Proceedings of the 1st Workshop on Haptic Human Computer Interaction*, 31st August - 1st September, 2000, Glasgow, Scotland, pp.54 – 62.

Brereton, Margot and McGarry, Ben. 'An Observational Study of How Objects Support Engineering Design Thinking and Communication: Implications for the design of tangible media' *CHI 2000*, 2000 http://tangible.media.mit.edu/courses/ti01/Brereton-Objects-CHI00.pdf.

Chesire, D. G., Evans, M. A., Dean, C. J.. ‘Haptic Modelling - An Alternative Industrial Design Methodology?’ *Proceedings of Eurohaptics 2001* pp.124-128.

Digital Clay http://www2.parc.com/spl/projects/modrobots/lattice/digitalclay/.

Guiard, Y., ‘Asymmetric Division of Labor in Human Skilled Bimanual Action: The Kinematic Chain as Model,*’ The Journal of Motor Behavior*, 19 (4), 1987, pp. 486-517.

Hinckley, K., Pausch, R.,. Goble, John C,. Kassell, Neal F.. 'A survey of design issues in spatial input.' *Proceedings of the 7th annual ACM symposium on User interface software and technology*, p.219, November 02-04, 1994, Marina del Rey, California, United States.

Robert J.K. Jacob, 'New Human-Computer Interaction Techniques'. Human-Computer Interaction Lab, Naval Research Laboratory, Washington, D.C., U.S.A. *http://www.cs.tufts.edu/~jacob/papers/asi.html.*

Parsons, L., 'Inability to reason about an object's orientation using an axis and angle of rotation'*. Journal of Experimental Psychology: Human Perception and Performance*, 1995, Vo1.21, No.6, 1259-1277.

Pereira, L. Q., 'Divergent Thinking and the Design Process' *www.id.iit/edu/~pereira/pr01.html*). pg 4.

Reachin Technologies AB, Sweden. www.*reachin.se.*

Römer, A., Pache, M., Weißhahn, G., Lindemann U. and Hacker, W. 'Effort-saving product representations in design – results of a questionnaire survey'. *Design Studies* Vol.22, Issue 6. 2001. pp473-491.

Schön, D.. 'The Reflective Practitioner', *Jossey-Bass, San Fransico* 1983.

Sener, B., Joris S. M. Vergeest and Evren Akar. 'New Generation computer-aided design tools: two related research projects investigating the future expectations of designers' *International Design Conference - Design 2002.*

SensAble Technologies Inc. *www.sensable.com.*

ShapeTape. Measurand Inc. (www.measurand.com).

Scali, s., Shillito, A.M., Wright, M. 'Thinking in space: concept physical models and the call for new digital tools'. 'Crafts in the 20th Century', Edinburgh 2002, http://www.eca.ac.uk/tacitus/papers.htm.

Shillito, A.M., Paynter, K., Wright, M. & Wall, S. Unpublished review paper includes statements on sketching by Temple, S., ('Sketching - Thoughts Made Visible', *Co-Design 10:11:12* - 1994. pg 20), Verstijnen I.M. and Hennessey, J.M.. ('Sketching and creative discovery'. *Design Studies* 1998 vol. 19 no. 4.. T. Purcell (ed.) Elsevier Science Ltd, Oxford. 1998, pg. 532)*.*

SUS: Brooke, J.. 'SUS: A "quick and dirty" usability scale.' In P. W. Jordan, B. Thomas, B. A. Weerdmeester, & I. L. McClelland (Eds.), *Usability evaluation in industry*, 189-194. London, UK: Taylor & Francis. MS Word: http://www.usability.serco.com/trump/documents/Suschapt.doc. 1996.

TLX: Hart, S. G. & Staveland, L. E.. 'Development of a multi-dimensional workload rating scale: Results of empirical and theoretical research.' *In P. A. Hancock & N. Meshkati (Eds.), Human mental workload*, 139-183. Amsterdam, The Netherlands: Elsevier. 1988.

Tovey, 1986, in Gribnau, M. 'Two-handed interaction in computer supported 3D conceptual modeling', *Doctoral Dissertation* , Delft Univ. of Technology http://www.io.tudelft.nl/id-studiolab/gribnau/thesis/PDF/chapter1.pdf.

Wall, S. A., Paynter, K., Shillito, A.M., Wright, M., Scali, S. 'The Effect of Haptic Feedback and Stereo Graphics in a 3D Target Acquisition Task'. *Proceedings of EuroHaptics 2002* , pp 23-29.

Ware, C. and Rose, J., 'Rotating virtual objects with real handles'*, ACM Transactions on Computer-Human Interaction (TOCHI)*, Volume 6 , Issue 2 (June 1999), ACM Press New York, NY, USA Pages: 162 - 180 ISSN:1073-0516.

Wiegers, T. and Vergeest, J.S.M. 'Extraction of Cad Tool Requirements from Industry and from experimental design projects', *Proceedings of ASME 2001.*

Zhai, S., Milgram, P., 'Quantifying Coordination in Multiple DOF Movement and Its Application to Evaluating 6 DOF Input Devices', *CHI 98 papers*. 1998.

CAPTIONS FOR ILLUSTRATIONS:

Figure 1. The three domains that inform the Tacitus Project: working practice, design and technology.
Figure 2. Creative process: germinal to practical phase.
Figure 3. Design conceptualization process: jeweller physically exploring form relationships.
Figure 4. Divergent, convergent and iterative activities in designing: models by Edinburgh College of Art Architecture students.
Figure 5. Digital Clay: individual modules able to sense others in an assembly.
Figure 6. Phantom force feedback device with six degrees of freedom.
Figure 7. Reachin System: space co-located with force feedback device .
Figure 8. Reachin System: space co-located with device and stereo glasses for 3D vision.
Figure 9. 3D space showing haptic plane, avatar of stylus for force feedback, floor of workspace and sketch of teapot.
Figure 10. Perfume bottle: the given object to sketch.
Figure 11. 3D Sketch of perfume bottle with haptic magnets on ends of lines (met).
Figure 12. 3D Sketch of perfume bottle with no haptic magnets on line (nht).
Figure 13. Detail of sketch of perfume bottle with errors created by pulling hard off magnets on ends of lines (met).
Figure 14. Suggestion by participant in 3D sketching study for improving interaction with magnets at ends of line.
Figure 15. Perfume bottle sketched using tool with magnets scattered along line. (hlt).
Figure 16. SUS ratings for the 3 experimental conditions – nht, met and hlt.