Designing for Engagement: Using indirect manipulation to support form exploration in 3D modeling

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This thesis aims to study the design possibilities for supporting explorative form-finding in 3D modeling applications. For today's many design professions, 3D forms are achieved partly in engagement with digital environments. Use of software has far exceeded final idea execution, extending to the early phases of design work in which the outcome is not predetermined. This insight led designers of interactive systems support sketching and ideating activities by reducing the risk of experimentation and cognitive effort demanded from user. Yet, there has been less emphasis on traditional design and craft practice that acknowledges engagement with materials and effort spent on work as an integral part of creative process.

The notion of exploration in the scope of this thesis attempts to incorporate such aspects. Relevant literature about workshop practice in design and craft has been reviewed, as well as examples of CAD technologies that aid designers. In this light, HCI perspectives on the design of creativity support tools and games have been discussed. The thesis work aimed to concretize this background by building a design strategy and an interactive artifact. A 3D form-finding application concept using objects in modeling space to indirectly manipulate geometry, “kfields”, has been developed and evaluated with users at various stages. The thesis concludes by reflecting on the findings of different design stages and proposing further directions for design.

**Keywords:** 3D Modeling, CAD, digital material, form-finding, craft, design, creativity support tools, vector graphics, interactive systems, engagement
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“The machine cannot be used as a short cut to escape the necessity for organic experience”

Lewis Mumford*

*quote taken from “The new vision”, Moholy-Nagy, 1946
I INTRODUCTION

Recent years witnessed an interest in user experience and engagement in human computer interaction going beyond traditional usability concerns such as efficiency and ease of use. Defining experience and engagement during use as design ideals suggests new directions for the design of interactive products.

One group of interactive products that I want to consider here are design tools, digital tools that aid people to design things.

Certainly, such digital tools are used to create and share designs. In this sense the main reason for engaging with digital tools is the result, in the form of concrete output. Yet, this is hardly the only significance of designer’s engagement with such tools. As Schön puts it, “design knowledge is knowing in action”; designers in their activities of drawing and making do not only register information but also construct its meaning (1992). Engagement with interactive tools is important not only for work-completion but also for gaining knowledge and reflection. I think this is also how design ideals such as efficiency and streamlining existing processes can be challenged and the notion of engagement can guide the design of such tools.

This pattern of thought is not new in design. As it will be mentioned later, emphasis on engagement has informed many design movements that called for a “return to the workshop”. In early 20th century mechanization brought great efficiency in production and rendered most craft production obsolete. Yet, workshop practice and craft methods were still valued in some contexts not for efficiency or ease of use, but for the holistic experience they provided. Workshop practice and engaging with different materials was perceived more than instruments to externalize what is in mind but have been used to invent and justify the design work.

This thesis asks how digital tools, particularly 3D modeling tools, can be designed with such motives. Certainly, experience and engagement are complex notions that are situated in relation to many elements such as physical space, social relations, body, materials, etc. In this thesis the emphasis has been on material qualities. Materials affect designer’s engagement in many levels, various materials give different responses to designer’s actions, in turn affecting how designer takes action to realize his or her intention. As it will be mentioned in the following chapter, how designer reaches his or her intention is not necessarily a matter of efficiency from the viewpoint of craft, but is also
significant for justifying the work. In addition to this, response of materials has potential to challenge designer’s initial intention and yield to unthought-of forms in the process. Yet, not all materials support justification and form exploration in the same way. One aim in this thesis is to identify how those two aspects can be supported through digital material. Contemporary designer spends a good deal of his or her time with software. If we accept software as a material for designer, it becomes crucial to ask how meaningful engagement with software tools can be facilitated.

Research question
This thesis aims to study the design possibilities of 3D modeling applications regarding their explorative role in form-finding. This explorative role has been framed in relation to engagement with digital material and how the response of the materials can facilitate forms that are not conceived at the beginning of the design process.

Thesis structure
CHAPTER 2 gives the background of the design space.

Section 2.1 introduces a few concepts about engagement and workmanship from the traditions of design and craft. In design and crafts workshop practice and handwork has been perceived as an integral part of creative process. Rather than implementing a preconceived form, those activities have been valued for reaching the form. The section discusses different approaches regarding their assessment of technique and individual workmanship.

Section 2.2 aims to map the above mentioned differences to various 3D modeling tools. Many modeling tools support individual workmanship by using the capabilities of digital medium. When it comes to user interaction, some technologies enhance the traditional ways of sketching, while some technologies replace manual work to a greater extend and provide higher-level, symbolic interaction modes to model.

Section 2.3 discusses HCI approaches for supporting creative work. In the domain of “creativity support tools” it has been acknowledged that users of digital systems should be able to explore different solutions in design processes, since many design problems are not precisely defined at the beginning of the design process. Solutions have been proposed to decrease the effort and risks of exploring different design solutions. At the same time, some approaches in
HCI differ from traditional craft view by making the distinction between creative tasks and interaction with computer. Notions of game and play are discussed to challenge this distinction. The section attempts to assess different approaches that aim to support creative activity from the point of engagement with material.

CHAPTER 3 explains the methods and approaches used in different stages of the design process. Section 3.1 aims to show the general approach in carrying out design work in the thesis. Sections 3.2, 3.3 and 3.4 show various methods employed at the first, second and third stages of the design process. Those stages show a progression of the design concept from early ideation to higher fidelity prototypes.

CHAPTER 4 documents the design process and user feedbacks in detail. Section 4.1 lays out the general design strategy that guided the design process at early stage and shows a few initial ideas.

Sections 4.2 is the documentation of a workshop carried out with participants who have experience with 3D modeling. The aim of this workshop was to make participants imagine form-finding mechanics for creating 3D forms and to identify key concepts in participants’ proposals.

Sections 4.3 shows the second stage of the design process. At this stage, one of the initial ideas that enabled indirect manipulation of geometric entities was selected for further development. This idea later led to the main design concept “kfields”, a modeling application which enabled users to manipulate geometry by using high-level variables. Those variables did not require any programming effort on users’ side and employed familiar ways of interacting with 3D objects in modeling space. By using them a number of geometric entities could be manipulated simultaneously, making it convenient for exploring different 3D shapes. This idea was prototyped and evaluated with participants in sessions. The feedback gained from this session led to the development of the final prototype.

Sections 4.4 shows the final stage of the design process. The main goal for this stage was to get information about how the prototype would be used in contexts that users determine. A prototype was developed that was robust enough to be left to participants. Also, a diary was provided to participants to
document their experience with the prototype. Finally, interviews were held with participants to clarify their documentation and get their overall feedback on prototype. Those feedbacks have been used to discuss the concepts introduced in chapter 2.

**CHAPTER 5** reflects on the findings along the process and discusses them in light of the concepts introduced in chapter 2. The discussions are followed by **Section 4.4** that shows possible directions to expand the design concept, kfields.

**CHAPTER 6** aims to draw some observations and reflections made along the previous chapters together.
2 BACKGROUND

2.1 Knowledge and form-giving

2.1.1 A historical account of knowledge and form-giving in design

It can be said that for practitioners of design and applied arts, their works are not arbitrary but also right and coherent. Perhaps one of the eras in which the concern for coherency was most pronounced was late 19th and early 20th century when the many movements of the time such as Art Nouveau, De Stijl and Constructivism appeared to create a new, universal style in reaction to the stylistic confusion of 19th century and by rejecting tradition (Heskett, 1980). One feature of those movements was their aim to embrace many fields of applied arts and achieve a common language among works. This vision also manifested itself in the pedagogical institutions of the time such as Bauhaus, which addressed the problem of unity in a systematic way and called for a return to workshop practice. In Bauhaus Manifesto (1919) written by Walter Gropius, the act of “building” was seen in contrast to isolated drawing and painting and has been related to a holistic view to unite arts.

Elevation of constructive activities of crafts against fine arts was not new. As expressed in relation to Arts and Crafts movement, “The bare bones, the nakedness and the restraint of craft were contrasted with the superfluity and thus the superfluousness and superficiality of contemporary painting” (Tillyard, 1988, p.30). Similarly, workshop practice and rejection of the isolated activity of painting was an important component of education in Bauhaus. As Gropius proclaimed in the manifesto, “This world of mere drawing and painting of draughtsmen and applied artists must at long last become a world that builds.” (1919). Yet unlike Arts and Crafts movement which rejected industrialism and called for a return to craft, the workshop pieces made by student in Bauhaus were not considered an aim in itself, but rather a part of education. The organic and holistic approach of craftsmanship was favored over the division of intellectual and manual labor. (Moholy-Nagy, 1947, p.20)

In its short history Bauhaus did not present a uniform approach to technology, nor a uniform understanding of tools. In the early years of school, tools were few and simple. Works by students, although showing a geometric vocabulary, were produced by hand and reflected the individual nature of creation (Wick, 2000, p.122). Yet, this later changed with the redefinition of the motto of
school from “art & crafts, a new unity” to “art & technology, a new unity”. A work, ‘Telephone Picture’, made by Bauhaus master László Moholy-Nagy before his arrival to the school well illustrates this:

In 1922, I ordered by telephone from a sign factory five paintings in porcelain enamel. I had the factory’s color chart before me and I sketched my paintings on graph paper. At the other end of the telephone, the factory supervisor had the same kind of paper, divided into squares. He took down the dictated shapes in the correct position. (It was like playing chess by correspondence.) … True, these pictures did not have the virtue of the “individual touch”, but my action was directed exactly against this over-emphasis. (Moholy-Nagy, 1947, p.79-80)

With the idea of the ‘Telephone Picture’ the aim was to eliminate the artist’s individual touch and get direct feedback from the production line. (Kaplan, p.121) Direct interaction with technology has been valued to avoid preconceived forms and achieve the unity between art and technology. Moholy-Nagy made the distinction between production (the creative use of medium) and reproduction (the transmission of content through a medium) (Margolin, 1997, p.139). Similarly, he advocated that photography should not replicate old ways of seeing but create new sensory experiences, and criticized many photographs of his time for being mimetic (p.141).

A motive supporting the use of new media and tools was to achieve artistic precision. Artists like Van Doesburg, Lissitsky and Moholy-Nagy were fascinated by the exactness of science. Avoiding manual work and individual touch was seen as a way to maintain objectivity, a reason why they favored photography as a means of production (Mansbach, 1980, p.39). While, the call for objectivism by some proponents of those movements can be called dogmatic and a predecessor of “scientific design” (Cross, 2001), practically oriented education and preliminary design course in various schools and the visual language developed by early century movements have been impactful.

2.1.2 Knowledge and craft

On the other hand, it would be wrong to think that relation between knowledge and form-giving can only be defined in terms of commitment to a medium or universality. Dormer rejects the aesthetic component of technology. “A lot of
new technology is similar in its freedoms; high technology can be dressed, not in new design but in old. Technology gives designers the freedom to rework past styles ad infinitum – that is why it does not dictate its own aesthetic.” (1993, p.52)

Dormer rather points to individual activity of rule-following rules that help craftspeople to achieve “honest work” (1997, p.221). “Rules of procedure” are personal and help craftspeople not only accomplish their task but also keep them on track. It is important to notice that rules of procedure are distinct from rules of making, which are more practically oriented. Following the rules of procedure is deliberate. Craftspeople avoid cheating, to maintain their “self integrity” and truth in their work. He gives the rule of not moving clay pellets from a portrait modeler as an example:

Second, if the modeler knows he is going to place small pieces of clay in position and never move them again then it makes him think hard before committing himself. His questions are: why am I adding this piece of clay here? Is it because it contributes to this part of the form? (p.223)

Dormer suggests that craft work, if practiced with discipline, is also “right” for the craftsperson. Yet it is hard to explicate this rightness. Learned through experience and as a piece of tacit knowledge, discerning good and bad design for craft work is a matter of connoisseurship. In this regard the claim for truth by a craftsman is distinct from the universal claims of modernists.

Dormer does not mention craft tools but acknowledges the contingent nature of engaging with hand work (Dormer, 1994). “Virtue of a conflict” makes craft work attractive and is related to the productive tension between the craftsperson’s desire to maintain a static intention and the “inevitable vagaries” of craft work (p.81). 1

A related distinction has been made by David Pye, who coined the terms workmanship of risk and workmanship of certainty. Pye defines the first so:

If I must ascribe to the word craftsmanship, I shall say as a first

1 Dormer refers to concepts of intention and process, described in art historian Michael Baxandall’s book Patterns of Intention.
approximation that it means simply workmanship using any kind of technique or apparatus, in which the quality of the result is not predetermined, but depends on the judgment, dexterity and care which the maker exercises as he works. The essential idea is that the quality of the result is continually at risk during the process of making; and so I shall call this kind of workmanship ‘The workmanship of risk’: an uncouth phrase but at least descriptive. (Pye, 1968, p.20)

Workmanship of certainty, on the other hand, is characterized by the opposite, predictable results. Pye distinguishes mass-production not by the lack of workmanship of risk but by the limitation of this kind of workmanship to the beginning of the process. To recount his example about carving types for printing: “But all this judgment, dexterity and care has been concentrated and stored up before the actual printing starts” (p.21) In this line of thought, many production processes supported by 3D modeling tools show the same distinction between the beginning of process and execution. 3D modeling can be considered as a type of workmanship of risk, since its quality is not predetermined and great care is needed to make good modeling. On the other hand, 3D modeling is also different as it takes advantage of digital material. Referring to Pye, McCullough asks if electronic medium possesses enough risk for workmanship and accepts materiality a crucial aspect for electronic craft. “Can a computer with its undo and save as functions ever demand sufficient concentration on our part to enable serious, expressive works to come forth?” (1996, p.212) The question of material and technique will be explored in more detail in the following section.

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The role of technique and individual workmanship in creative activity is much-debated. One question is whether the accuracy and novelty of a work lies in technique or in individual workmanship. Avoiding individual touch and using mechanical means of production such as photography have been preferred to achieve accuracy. “Telephone Picture” is interesting regarding that it has turned the real-time, tangible, fluent interaction of painting into a much less fluid experience. It has been suggested that human computer interaction incorporated an increasing breadth of human skills throughout its development to be accessible to a wider public (Dourish, 2004, p.14). Yet, arts and design also deliberately constrained the tangible skill set of artist, as in the case of “Telephone Picture” to achieve reproducibility and scalability.
At the same time workmanship of risk has been valued, since it demands concentration and skilled participation. An interesting concept to consider is the aspect of “conflict”; craft work does not always yield predetermined results, partly because of the tension between craftsperson’s intention and the nature of working with materials. In creative processes, Schön calls the consequences that are discovered alongside the process “unintended consequences” (1992, p.6).

Of course, technique and manual work do not exist in isolation. As Pye states workmanship of risk in its “pure form” is hard to find, many trades use aids that eliminate certain risks. It will be mentioned in the following section that in design, similar aids exist in drawing, such as grids, constraints, Bézier curves in digital modeling or draftsmen’s wooden spline. Those techniques have been used to aid designers and draftsmen eliminate certain risks and achieve quality.

In this project one aim has been to consider digital material both as an aid to model geometry but also to limit control and leave space for unexpected results that might emerge during the interaction with program. It has been anticipated that in those cases conflicts might emerge that challenge user’s intention or approach to modeling. Such conflicts afford the possibility to explore forms that are not foreseen at the beginning of the process. Acknowledging the productivity of such conflicts as in craft gives interaction designers the opportunity to support designers not only by enabling fluent form-giving and freely sketching, but also with environments that involves indirect ways of modeling 3D forms.
2.2 Design Materials

For designers one source to draw inspiration from and justify design work has been material. Working with different materials and employing their contrasts was an important component of the education in Bauhaus (Moholy-Nagy, 1947; Itten, 1975). In addition to this, named as “truth to materials”, it has been common for some movements like Arts and Crafts and early modernism to value the handling of material that is unpretentious and suitable to the nature of the material (Tillyard, 1988). A good example of this ideal is direct carving as opposed to modeling beforehand in sculpture. The term direct carving refers to the direct engagement of the sculptor with the material by cutting or carving it rather than preparing a model or a sketch. As Zilczer puts, “While academic sculptors continued the nineteenth-century practice of making small-scale models to be enlarged and carved by assistants, many progressive-minded artists and critics advocated that the sculptor himself must carve his work without assistance or preliminary models.” (p.44). This approach was related to craft practice and resistance of carved material was contrasted to malleability of molding. The material quality of stone directly determined artist’s engagement.

Yet, claims about truth to material have been questioned in the domain of design regarding the importance of scale and economy rather than material in determining form (Pye, 1968) and the advances in materials and production techniques that have rendered the unity between material and form irrelevant (Dormer, 1993).

The question of material is challenging when it comes to designing digital artifacts. Löwgren and Söderberg argue that digital technology is a “material without qualities” (2007, p.3), and emphasize the constructed qualities of information technology rather than inherent qualities. In relation to computer-based tools, Ehn argues that it is in designers’ disposal to create the material for skilled participation: “we not only design the new tools, we also design the material for the skilled worker to work with.” (1988, p.381) This brings a tension for the design of digital tools. Even though digital material itself is considered without qualities, the work of interaction designer has some qualities.

At the same time the word material does not always refer to raw materials but also to qualities that are constructed. As Vallgårda and Redström state, distinctions between material and structure or material and product are blurred and depend on the point of view (2007). What is accepted material by a
designer might be a structure or a finished product for an engineer. Also, material qualities in physical sense are not necessarily meaningful to assess user experience. For example, when Schön mentions how the differences of three construction systems “LEGO, Tinkertoys and Modula” (1992, p.9) afford different construction relationships it is more about the structure of those materials rather than their raw material plastic. Materials influence the designer by their behavior and structure. “Although it was a designer’s appreciations that determined which pieces he/she wanted to connect, his/her ability to connect them depended, at least in part, on the behaviour of the pieces themselves” (p.11) In this section the concept material is mostly discussed by referring to specific qualities of software rather than computation in general. Software mechanics creates the interface between computation and user through user interface and geometrical construction. In this regard software can be regarded as one of the main elements that effect user’s engagement.

### 2.2.1 Different materials: Modeling

3D modeling tools make use of computing in different ways, constructing different materials for the user. One main distinction in 3d modeling is between mesh and vector based surfaces. This distinction can be compared to the difference between pixilated and vector based images. While mesh surfaces derive from a cloud of points, in vector based modeling programs surfaces and solids are generated by mathematically defined curves.

Here, I will focus on vector based modeling which is more frequently used for architecture, industrial design and related fields and which is mostly classified under CAD software. This section is not an attempt to introduce all CAD concepts; but a few key concepts that have been influential in this project will be mentioned. As a work material CAGD (computer aided geometric design) or commonly CAD² (computer aided design) programs became available with the emergence of a few technologies such as cathode ray tube displays, computers and pointing devices (Farin, 2002; Cohen et al., 2010). Ivan Sutherland’s pioneering work “Sketchpad” realized at Lincoln Laboratory demonstrated the effectiveness of pointing device as opposed to typing in

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² By definition CAD encompasses many other design areas such as circuit design and some resources distinguish CAD which is aimed towards drawing by naming it as CAGD or MCAD (mechanical computer aided design).
numbers (Sutherland, 1964).

Another ground-breaking invention was the various computational definitions of free-form curves (non-circle curves) such as Coons-patch and Bézier curves. Schemes developed first by Casteljau and then Bézier (at the time working in automotive manufacturers, Citroën and Renault respectively) became especially popular due to their construction. Although their algorithms are different, the basic idea was same: rather than controlling curves by points on the curve, their system made use of “control points”. Control points do not directly control the curve but are situated near the curve and a curve follows the points in an optimal way. Now known as Bézier curves, this technology enabled draftsmen without extensive mathematical training to design surfaces (Rockwood and Chambers, 1996, p.16). These schemes also influenced the foundation of “basis splines” which became widespread in CAD programs. Cohen et al. relates the success of Bézier and de Casteljau methods over other mathematical constructions to their aesthetically pleasing properties:

Unlike nearly all other schemes based on interpolation formulations, these two French schemes generated curves theoretically guaranteed not to introduce any undesirable, historically vexing, extraneous shape undulations. These extraordinary properties, virtually unseen previously in CAD applications, quickly attracted mathematical interest in gaining fundamental understanding for their attractive behaviour. (2010, p.3)

Farin notes that, earlier draftsmen used a mechanical tool known as spline that was used to achieve a similar parametric effect. This was a flexible piece of wood that was bent by using metal weights. “A spline “tries” to bend as little as possible, resulting in shapes which are both aesthetically pleasing and physically optimal” (2002, p.7). Digital spline curves are based on similar design principles yet they are computationally reproduced by mathematical approximation.

Creating non-uniform surfaces is based on a similar logic. B-spline, Bézier or NURBS (non-uniform rational basis spline) surfaces refer to different constructions. Yet, like Bézier curves and b-splines their construction is based on control points. When creating surfaces from input curves, control points of the resulting surface are calculated by moving the input curves in space. Both curves and the resulting surface have a geometrical continuity degree. It is common for CAD software companies to market their products as ensuring
“class-A” surfaces (surfaces with high degree of geometric continuity), since surface flow is very important for many industries, especially for automotive and marine vehicles.

Another important feature for CAD software has been to support parametric models. In parametric models geometric entities have parameters that control their geometries and position in space. Such geometric relations can be the distance between two points, a certain angle between two lines, etc. Those relations enable users to modify the model by using high-level parameters without doing much manual work. Parametric models sometimes require planning of higher-level variables in advance. They have been used for quickly responding to changing specifications in engineering design. As Shapiro and Vossler state:

In modern systems, solid models are defined and manipulated through high-level, parameterized, and user-modifiable definitions; such definitions are called “editable” in [HJ93]. These interfaces allow users to modify solid models quickly by changing a few predefined parameters that supposedly have direct bearing on various engineering characteristics of the modeled mechanical device. (1995, p.43)

Parametric models mostly support “history” function that enables them to modify the model based on changes. This can be seen as an extension of parametric functions in time scale. For example, if user has generated a surface from curves and later changes one of the input curves, the surface automatically updates. Similarly if a hole is defined in a specific distance from a center point, its position will also change if the position of center point changes. Especially in later product development, using history function aims to reduce the risks associated with changes in design and avoid extra work.

Those developments mentioned are mostly concerned with geometric construction and relations for describing digital modeling material. Yet, it is useful to mention that modeling applications have been created to directly address physical material qualities in digital medium. Form-finding by using physical simulations is common, mostly to design membrane, trust or tensile structures\(^3\). These simulations are realized by using parametric relations

\(^3\) The term “form-finding” is attributed to Frei Otto, who experimented with
between entities and have been employed both for geometric exploration and structural performance (Shea et al., 2005). In addition to simulating materials, work has been carried out to include material organization and design in the form-finding process (Oxman and Rosenberg, 2007). Of course, material simulation and geometrical construction does not directly translate into material users engage with. In the following paragraphs different interaction modes will be introduced.

**Modeling interfaces**

Material aspects of modeling software are not only limited to their mathematical construction. Users can interact with and create their models in various ways, such as manually sketching curves or symbolically generating models. Some technologies aim to use designers’ expertise in traditional media and enhance activities like sketching. For example, spline curves do not necessarily need to be created by determining control points. Many 3D product development program families offer the functionality to convert hand-drawn curves into splines, by computationally optimizing them. Such products have been recently introduced to the mass market, yet were investigated as early as late eighties. Banks and Cohen (1990) point to the intuitive qualities of hand sketching and propose creating spline curves from interactively sketched curves. Baudel (1994) states that graphic designers do not think in terms of control points when it comes to creating curves and proposes a gesture based interface for drawing and editing curves by stylus. Since those early attempts much work has been carried out to convert hand-drawn data interactively into basis splines. A state-of-the-art example, ILoveSketch (Bae et al., 2008), provides intuitive sketching in virtual 3D space as well as a set of gestures to join, edit, delete and manage curves. Those technologies aim to optimize hand-drawn curves and integrate hand-sketching into digital workflow.

On the other hand, some methods such as generative modeling eliminate manual work to a great extent. In generative models shapes are represented not as objects but as operations. Those operations also create shapes procedurally. To give a definition:

A shape is generative if it has a representation that is not only a list of geometric primitives, but which follows the principle of information membrane and pneumatic structures (Oxman and Rosenberg, 2007).
unfolding. This means that the shape can be appropriately described by comparably few high-level data, from which a great number of low-level data (e.g., geometric primitives) can be generated, possibly even on demand. (Havemann, 2005, p.26)

Generative modeling uses the power of computation to repeatedly or recursively generate geometries that are hard to obtain by manual input. Those qualities attracted attention and generative modeling has been used to model manually hard to model shapes such as fur on an animal (Snyder and Kajiya, 1992). Early generative models have focused on coding, but over time other types of interaction modes emerged such as visual programming. It should also be mentioned that not all generative modeling depends entirely on functions. It is common to modify or transform manually created shapes by using generative modeling. In addition to this, generative modeling can be enhanced with interactive elements. For example, colloquially called attractor points, points can be used to modify entities in modeling space by moving a point. Attractor points are mostly used to control a grid of objects and interactively create fields of gradual change. For achieving this effect, designer first constructs the underlying structure by programming and then assigns a point in the modeling space as a variable. So, user is able to move the point in the modeling space rather than typing numbers and parametrically control the model.

Generative modeling has been employed for many reasons. Some of them are efficiency related: generated models occupy less space since modeling data is created on demand and generated models make it possible to create geometries that need precision or repeating structures. Yet, there has also been an interest in generative modeling to aid design processes by providing many design alternatives based on parameters or rule systems. In this case software is perceived more as a partner of design rather than a basic aid. For example, in architecture the approach “shape grammars” is employed to analyze and design different forms (Knight and Stiny, 2001) that can be generated from a common rule set. Knight and Stiny mapped Frank Lloyd Wright houses as variations of design rules and similarly generated design alternatives for a school building by using computation. Realizing such variations manually takes time and some variations might be missed out if the process is manual. The

4 “Shape grammars” is a term used by Knight and Stiny in 1971 to describe non-representational art in a formal, rule-governed way.
advantage of computation in this case is the emergence of unexpected design alternatives.

Until now different modeling methods have been described. These methods and features described are not isolated from other methods. There are many programs where different working settings such as parametric and non-parametric or manually determined and procedural modeling can co-exist. A user can choose to work parametrically or not, or can extend the program by small pieces of code to automate some tasks. Users can also switch between different kinds of input such as between drawing tablets and mouse or incorporate their sketches scanned from paper to the modeling environment as background, mesh surfaces can also be incorporated to the modeling environment. So, it is possible to work in a heterogeneous environment.

Technologies described also demand different amounts of effort. For example, generative modeling interfaces can be regarded as increasing the cognitive effort for modeling. On the other hand, it is possible to say that they make it easier to model since they rely less on manual dexterity that characterizes hand-sketching interfaces. So user skills play an important role in determining which interfaces are more demanding.

It should be noted that, in general, CAD technologies replaced tangible technologies such as drafting with paper and brought a great increase in efficiency. Tedious activities such as creating section or perspective views became trivial tasks for users. At the same time this came at the cost of some skill loss as Henderson recounts the concerns of older draftsmen (1998, p.144). As users of those systems did not have to engage in mathematical activity, they knew less in a traditional sense and an important part of foundational knowledge was lost.

Yet, it would be wrong today say that CAD / CAM (computer aided manufacturing) technologies have completely replaced skills in all fields. Software is able to provide real-time perspective renderings of geometry but, many design students still go through the laborious activity of learning how to draw in perspective. Computer controlled machining of wood or other modeling materials is common for prototyping, yet many design students still carve out wood or make paper mock-ups of their designs. So, those activities are not significant solely for getting the work done but they also facilitate
learning about geometry, vision and are thought to be inspiring as sketch tools.

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Contemporary 3D modeling software used by designers demonstrates a wide spectrum between intensive manual work and computer support for form-finding. While some modeling techniques are intensively manual, enabling the modeler shape the 3d model like a piece of clay, generative modeling requires scripting or visual programming, even making use of mathematical formulas. Some differences mentioned earlier like production-reproduction or mimesis-construction can be mapped to different practices of 3d modeling, such as intuitively sketching like on paper or exploring different forms by using the capabilities of computing. Many contemporary applications already support form-finding by generative tools or physical simulations, but user engagement with those tools are not always addressed in the literature.

When the emphasis is on user engagement aspects such as control and consequences of interaction become crucial. Some technologies mentioned above are oriented towards aiding user in achieving foreseeable results while some offer user unintended results.

In this project the emphasis was on modes of interaction that are intended to create situations that yield to unintended consequences. So, it was thought that very direct and precise controls might not be suitable for this approach. An interesting aspect of engaging with materials can be the possible conflict between designer’s intention and the response of material like in craft. Design strategy (introduced in section 4.1) aimed to introduce such conflicts and indirect control of geometry was explored in design ideas. Indirect control here does not imply that user’s interaction with modeling material is indirect but rather that user’s manipulation of his or her work is through other objects or functions. Also it does not refer to complete automation or loss of craft. McCullough thinks craft practice in an abstract sense and sees control of the process as the essential component of craft practice, “Processes may be indirect, and mechanical and powered, so long as they are under manual guidance.”(1996, p.66). In this regard, many aids used such as splines or grids already make the process mechanized and indirect to a certain extend. Yet, they are not necessarily unpredictable. Design approach in this thesis aimed to employ indirect control especially to facilitate unintended consequences to explore forms that are not foreseen at the beginning of the process. This is
explored further in section 4.1, with concepts in which user does not control geometry precisely, but uses objects for manipulation.
2.3 Engagement with representation and material

This section gives account of several approaches concerning how design activity can be supported through software. Contemporary approaches for designing tools to support design acknowledge the complex nature of design problems and aim to support reflection and variance in design process. The aim in this section is to position the approach adopted in this thesis by discussing the various standpoints that are partly determined by what is thought to cause reflection during the process. A distinction identified is between user’s and material’s role in leading to circumstances that result in reflection and challenges. This can also be roughly translated into whether user’s reflection should be seen as an engagement with his or her representation or digital material. To discuss this distinction the concepts of game and play will be mentioned alongside creativity support tools.

2.3.1 Creativity support tools

There has been an interest in HCI to evaluate the design of tools to support creativity. Not all of this literature is directly concerned with designing material for creation. Just to give a few examples, Shneiderman proposes a general framework including collecting and disseminating the ideas alongside creating (2000). Lubart mentions plural possibilities for the computer to support creative work and proposes four different roles for computers such as nanny, pen-pal, coach and colleague (2005). Those roles are not always related to creative work directly and also represent side tasks such as time management and sharing. Yet, in relation to the role of computer as a colleague, he mentions the power of computers in generating random or heuristic variations.

One aim in the design of support tools has been to facilitate divergence and reducing the risks associated with experimenting in early phases of creative work. Terry and Mynatt (2002) see creative activity as a reflection-in-action and oppose the “Single State Document Model” that defines a document as having one state at a time, thereby imposing a linear logic for creation. Although many design projects involve more than a single correct solution in early phases (Terry et al., 2004), undo functions support only a single line of history in most software. Several design works have been realized to address this issue. Parallel Paths (Terry et al., 2004) enables users to work in multiple variations and modify them simultaneously. Designer’s Outpost (Klemmer et al., 2002) aims to manage different variations of web design concepts by displaying history in a visual form and implementing a history access interface. Klemmer et al.
mentions that chronological order of actions is not manifested in the concrete design artifact, making hard to understand the “design rationale” that has guided the design decisions. So, one aim in implementing history access and visualization has been to instantiate the earlier variations to convey design intentions in collaborative work settings.

Taking their cue from Schön and the hermeneutic view of design by Snodgrass and Coyne (1997), Yamamoto and Nakakoji stress on the importance of software talking back to the user in creative tasks (2005). Their main departure point is the insight that creativity support tools are not only significant for making final representations but also as thinking tools. The tool influences what kind of preliminary representations can be created by the tool and thus the reflection-in-action of users. Yet, from this point on they specify the design ideal as decreasing the cognitive source the tool asks for, and thus maximizing the cognitive sources spent on the creative task. “Interaction needs to be designed so that a user has a discourse with a representation, not with a computer system.” (p. 523)

At this point, the distinction between representation and computer system needs elaboration. One important question seems to be whether the “unintended consequences” described by Schön should be the consequences of user’s actions or of the behavior of the material. In some processes such as craft it seems hard to define the line. As Dormer has touched upon in relation to the concept “honest work” mentioned earlier (1997), the effort a material demands is not necessarily perceived as negative but also stimulating. Perhaps, this dichotomy is partly due to the generic connotations of “computer system” as opposed to dedicated software. One aim in this project is to understand whether digital tools can be designed to demand user’s effort, yet in a meaningful way.

### 2.3.2 Games and challenges

Earlier it has been mentioned that one aspect that makes craft work valuable is the conflict between the intention of designer and the contingent nature of working with materials. Games also address such conflicts; reaching a goal in a game is not trivial and requires effort. We can say that game rules or mechanics are the main sources of the conflict, and have the potential to challenge player’s intention. In this sense games exemplify how the reflection-in-action can be
viewed not only as a conversation with representations but also with program mechanics. It will later be shown in section 4.1 that this aspect of games, requiring effort and thinking of player, guided the initial design stages.

**Open Ended Games**

Open ended simulation games like Simcity, Civilization, and Sims are perhaps most close to content creation tools. They lack a clear narrative structure and demand players’ participation to define challenges. It has been demonstrated how additional rules can be put into use or creative authoring patterns can emerge if the game is relatively easy (Kirman, 2010). Iversen (2005) discusses how challenges can be freely identified in Sims and fit into the existing rule structure of the game. Iversen defines the notion of challenge broad enough to cover open ended games: “a situation of resistance that calls for transformative action in order to be resolved, and which either requires enough effort on behalf of the challenged to be non-trivial or whose outcome is not certain from the outset”. This definition is also parallel to the earlier mentioned definition of “workmanship of risk” in which “the quality of the result is not predetermined, but depends on the judgment, dexterity and care”. So, for the scope of this project we can accept challenges as moments where such effort is needed. One important point in game context is the games role in creating “resistance” situations; games create their own limits for reaching the goals.

What this literature points out in relation to this work is that the line between games and digital tools is blurred, open-ended games being a gray area. No doubt, these environments do not offer the same width of options as productivity software does. Yet, some works take advantage of this aspect of games. A portrait of Elvis Presley in Farm Town (Kirman, 2010) or Starship Enterprise built in Minecraft are powerful works as they refer to a process that involves using limited means of game mechanics. Such works can be best understood by the people who are knowledgeable about those games and are able to see the work in terms of the qualities of medium and effort taken by the player. Psychologist Jerome Brunner mentions that relevance to a certain rule set is at the heart of what he calls “formal surprise”:

*Take a hand of bridge. Any hand is equally unlikely. Some are extremely interesting – all spades, for a case. What makes such a hand interesting is not its improbability but its relevance to a rule structure. That feature is at the heart of formal surprise. Suppose one produces a solution to a*
mathematical problem that is within the formal constraints of a rule system, yet is shockingly new and yet obvious (once done). Almost inevitably, such a product will have both power and beauty. (Bruner, 1976 cited in McCullough, 1996, p.234)

**Non-game Software and Games**

Recently, there has been a tendency in HCI to go beyond usability concerns and address experiential and engaging qualities for designing interactive artifacts (Blythe et al., 2003; McCarthy and Wright, 2004). Blythe et al. challenge the ideal of “ease of use” for products and state that challenging and playful qualities can result in enjoyable experiences (p.11). The term “gamification” has been used to address many diverse approaches that aim to integrate game elements to non-game software and improve user experience (Deterding et al., 2011)

Comparison between games and productivity software is not new. It can be said that most HCI literature took a pragmatic stance and focused on the individual features of games. In early 1980’s Malone (1982) pointed out the success of games in creating captivating interaction and suggested the use of three concepts, challenge, fantasy and curiosity to make non-game software more enjoyable. His cases range from audio-visual effects to more constitutive design decisions. Malone exemplifies the use of those concepts in relation to complexity. Some examples he gives, like the use of game-like level structures in order to deal with the complexity of tools, are aimed towards managing the complexity. Yet, he also suggests the use of curiosity to challenge the “complete, consistent, and parsimonious” knowledge of users. So, Malone advocates for not only decreasing the complexity but also for increasing it for certain situations.

Another aspect of games that was related to productivity software in eighties has been “direct manipulation”, a term put into use by Shneiderman (1983). Shneiderman cites arcade consoles as a design ideal considering their fast response and predictability of manipulation, as opposed to command-line interfaces. A similar quality has been identified by Brenda Laurel (1986) as “first-personness” in interactive fantasy worlds. First-person interfaces “encourage the user to feel himself to be an agent in the mimetic action” (p.93). Laurel also regards constraints on first-person agency as an essential component of creativity in interactive fantasy worlds as long as they do not
decrease the first person feeling.

In addition to borrowing features from games, it has been argued that games and productivity software are fundamentally different. Pagulayan et al. (2003) stress on the differences between game and productivity software; whereas games are assessed based on the quality of gameplay, productivity software is assessed by the end result and enabling users to experience their own creativity. Malone (1982) maintains the distinction between “toy” and “tool” and sets the ideal for tool to be invisible. A main aspect pointed out is the contrast between intrinsic challenges that characterizes game play and external challenges that characterize productivity software.

An aim of this thesis is to reconsider this distinction and explore how the challenges in games can support designers much like working with materials supports designers in the activity of constructing design knowledge. From this perspective, the conflict between the static intention of designer and the contingent nature of craft can be seen as parallel to the conflict between the goal of player and the challenges that emerge based on the limited means of a game.
3 METHODOLOGY

3.1 Research through design

The research approach employed in this project is design-led; it aims to create a preferred perception of modeling tools. In design literature a few terms are used to describe the activity of research that is driven by design. “Research through design” (Frayling, 1993) emphasizes the knowledge achieved through design and communicated by an accompanying report. In the domain of HCI, Zimmerman et al. (2007) builds on this concept by pointing out to the benefits of making research that produces artifacts as the outcome of the design. Research through design employs the strength of designers in creating artifacts and embodying a certain preferred situation as an artifact for dissemination of knowledge.

Koskinen et al. propose the term “constructive design research” (2011), in which the construction of an artifact is central in building knowledge. Constructive design research is not user-centered or fieldwork inspired in traditional sense. In studying the material world researchers are interested “in a very special kind of make-believe world, which is partially their own creation” (p.79). This creation is not necessarily a finished tangible object but can include scenarios, mock-ups and a detailed concept.

At the same time, the term is distinguished from “research through design” with a more systematic focus, involving the methodological and theoretical knowledge gained along the process. Koskinen et al. emphasize the importance of research programs in systematizing the design work. Programs are built around a core that guides design work, in this way similar to research questions. Yet, as Redström (2011) mentions in more detail, design research programs are different from design research questions since they also include underlying proposals that shape the experimentations. Developing a program involves concretizing, interpreting and reinterpreting the program by carrying out experiments that are realized in specific contexts.

The scope of this project perhaps falls short of framing the underlying assumptions as a program, yet I have tried to translate such assumptions into action in different stages of the project. One guiding principle was to view form as an achievement that is the result of user’s interaction with a digital environment. This assumed that 3D form is not completely defined at the
beginning of modeling and users can negotiate their designs with the material they work with. This implied that reflection-in-action is not only a dialogue with the representation of the work but is also a dialogue with the material. Another principle was to evaluate design work through form rather than end use or functionality. It would be wrong to say that those assumptions are valid for all design cases and should guide the design of all design software tools. Yet, in the scope of this project those assumptions gave the opportunity to explore different and possibly challenging ways of interacting with modeling software.

3.2 First stage: Ideation and early sketches

Early stage of the design process was guided by the background research on engaging with materials and 3D modeling software as a material. It was after initial sketches that the theme “form as an achievement” has been selected to guide future design work. Achievement refers to user’s engagement with 3D modeling application in which there is no direct way to model what is in mind, but it requires effort to figure this out. The concept achievement here should not be confused with the concepts of achievement systems as it is used in game design. Achievement in the context of this thesis does not refer to a reward system external to the work. It is a perspective that views design work itself as an achievement rather than a given in design process. More specifically, achievement here implies a dialogue with the mechanics of software to reach the design work.

3D modeling environment ideas were developed where users need to use indirect ways to model. In this phase design focus was not much on traditional usability concerns such as efficiency and easiness associated with productivity software. The main aim was to introduce aspects such as challenge and loss of control to the modeling environment.

To further explore the theme “form as an achievement”, a workshop was held with a group of participants who are knowledgeable about various genres of modeling. One concern for constructive design research when it comes to involving users in early stages is the limited scope users might have about possible solutions (Koskinen et al., 2011). Thus, it is crucial to facilitate users’ imagination for alternative approaches. While preparing and facilitating the workshop, effort was spent to make users feel less concerned about the above
mentioned usability issues. Several ideas have been considered in this stage such as framing the activity as “3D modeling game design” rather than “3D modeling software design” and letting the participants imagine modeling games only for a single design work, to eliminate the concern for universality. Those exercises also aimed to make participants share the understanding of “form as an achievement”, since they had to invent game mechanics from finished design works.

3.3 Second stage: Experience prototyping

Keeping the outcomes of the workshop in mind, one of the initial design ideas was selected for further development. To test the idea together with target users a prototype was prepared that displayed the basic functions of the idea. The main aim at this stage was to simulate the experience of using those basic functions rather than making a complete working prototype. Buchenau and Fulton-Suri mention the usefulness of experience prototypes that are prepared to experience a certain situation without replicating the real circumstances or technical features (2000). One of the aims for making experience prototypes is to explore and evaluate ideas with future user groups. With similar intentions, a software prototype was prepared by using an available quick prototyping platform and the prototype was tested with 4 individuals in separate sessions. The concept and basic functions of the prototype were briefly introduced to the participant at the start of the session. Yet, during the sessions it became apparent that participants at some points had different assumptions about the functions that were displayed in the prototype. These cases turned out to be crucial for getting user insights and adapting them at the later stage.

In the sessions participants were encouraged to think aloud, asking questions and making comments about the prototype. Also, participants’ interaction with the prototype was screen-captured for documentation and further analysis. After the prototyping sessions, users were interviewed to get further insights and ideas.

3.4 Third stage: Prototypes left to users

In the third stage the emphasis was given on contextualization and the research aim was to explore the tensions between the intention of designer and the material quality of a digital tool. It has been thought that a self-controlled, extended experience of a prototype could be more appropriate for exploring
this tension. There are a few methods to understand users’ perception and experience in actual contexts. Koskinen et al. refer to the notion of platform (2011, p.137) that enable researchers to find out how new technology is adapted by users in daily contexts. Platforms are robust and maintenance-free enough to be left to users for daily use. Building on the experiences from earlier stages, similar qualities were aimed when making the prototype for the third stage yet the evaluation period was much shorter than the expected amount in platforms.

Gathering data and maintaining engagement become important tasks when prototypes are simply left to participants, since researchers don’t have a strict control on the activities carried out. For this stage in the project, data gathering relied on users’ own participation. The main reason for this preference was the situated and subjective nature of information that was aimed to be acquired from participants. Considering this, an accompanying diary was delivered to the participants.

In design research methods of using self-documentation exist such as diary studies and probes. Diary studies are mostly used for their advantage in capturing data in situ and supporting the memory of participants during the interview since many situations can otherwise be forgotten (Rieman, 1993; Carter and Mankoff, 2005). The reason for their utilization can be gathering data to inform the design of new products or evaluating the usability of novel products. Diaries can be prepared in different media such as paper, voice, video, photo diaries. They depend on participants’ own effort for documentation, yet the type of data that is going to be documented is mostly determined by the researcher. For example in the area of computer-related learning, Rieman asks participants to fill in “eureka reports”, where participants document the moments when they feel that they have learned something, solved a problem or made an unsuccessful attempt to do those (1993). Mostly, diaries are designed to accompany another task with minimum influence and one concern among researchers has been the interruption and influence caused by them on the activity being performed (Czerwinski et al., 2004).

Probes also depend on user participation through self-documentation. Yet, as in the concept cultural probes (Gaver et al., 1999), the main goal of probing is not to gather an objective view but an “impressionistic account” to inspire the design process. As Mattelmäki puts in relation to the work of Gaver et al.,
“Unlike the traditional self-documentation in ethnography in which existing activities are supposed to be documented with as little disruption as possible, and without interfering in them, this was specifically an attempt to provoke people and stimulate their imagination.” (2006, p.43) Probes are defined by their exploratory character and emphasis on personal context and perceptions. Over time, other types of probes emerged that are less oriented towards inspiration and are more focused on a solution area. One example is technology probes (Hutchinson et al., 2003) that display certain core functions to facilitate users’ creativity and have data logging capabilities. An important aim in technology probes is to facilitate possible users’ participation in the development of a novel product.

The diary prepared for this stage of the project aimed to capture various moments that might be experienced during the use of the prototype. In this sense it was more like traditional self-documenting. Yet, various moment descriptions have been determined in the diary, partly to influence the activities of participants, since participants were assigned to fill in at least five different moments. One shared aspect with probes was the intention to evoke participants’ insights during the use.

Diaries were collected back from participants roughly after a week in average and interviews were conducted. Using data documented by participants in interviews is common in diary studies as elicitation interviews (Carter and Mankoff, 2005) or as follow-up interviews for probes (Mattelmäki, 2006). During interviews researchers gain a better understanding of the material gathered and participants can use the material to make their points.
4 DESIGN PROCESS

4.1 Design strategy

Design Aim
One of the aims of design was to introduce challenging qualities to the work. Yet, the main idea in introducing such qualities was that, they would result in reflections where users reconsider their approach rather than thinking that the tool is insufficient. Games are particularly good at facilitating such an attitude, as in well-designed games users don’t attribute challenges to the insufficiency of games but iterate willingly to reach their goals. Making challenges meaningful for the users of 3D modeling programs was the main aim of design. Keeping the idea of form as an achievement in mind, several aspects of interaction in 3D modeling programs has been reconsidered.

History
3D Models have a history as they do not only represent a possible idea but also signs of workmanship such as actions carried out by user. This also enables to think of effort spent in building the model not as a negative aspect, but as a potential. One idea can be to use this potential by keeping the elements used to create the model interactive. In modeling it is quite common to dispose foundational elements such as arcs, rectangles or solid primitives once they are used to construct 3D models. Yet, considering that those elements are not only valuable for constructing the model but also for giving insights about its form, it can be fruitful to keep and make those elements represent some qualities in the work.

Control
Thinking in terms of processes and challenges gives opportunity to experiment with forms of controlling the model that are not necessarily direct or easy. From a game point of view, achieving the goals easily and directly is not necessarily desirable since it does not always facilitate good game experience and satisfaction. Conflicts that might emerge because of the intention of designer and the behavior of work environment can be productive.

Consequences
In most game mechanics actions of player have consequences that affect the general context of game-play. The effect of game elements cannot always be limited to certain entities by the player, as it would trivialize the game. Elements
having such consequences beyond their intended use can be surprising and challenging for designers.

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Thinking about design work as an achievement rather than a given for modeling environment has been thought as a productive way to generate ideas. To clarify the design strategy, a few alternative ways to explore forms have been sketched considering the aspects mentioned above.

4.1.1 Early concepts

**Primitive control**

One idea that emerged considering history was to keep history elements throughout the design process in a visually expressive and interactive mode. In 3D modeling it is common to delete primitives like circles, arcs, rectangles once they are used to create more complex entities like surfaces and polysurfaces. The aim in this sketch was to elevate those discarded elements to interactive objects, which can be used as widgets to modify the model.

**Force fields**

Another idea was to deal with curves and other shapes as achievements, so rather than building them at once, the procedure was to influence them with external elements. In this sketch, users define fixed points for their curves, but to create changes in the curve they needed to add external elements that were interactive and that were able to control more than one curve or surface.
Real-time modeling

The final idea mentioned here was a real-time simulation game like modeling environment, where elements and curves are not formed at once but rather grow until they are stopped by the user. At the same time they can be influenced by other elements. The growth process offers users alternatives and the autonomous growth of elements can yield to unexpected results.

FIGURE 11. Forcefields application both in 2D and 3D. Sliders on the top of pictures adjust the power of modifier

FIGURE 12. Some entities growing slowly.
4.2 “3D Modeling Game Design” workshop

After having set the concept of achievement as a theme for design, a workshop was planned to share the theme with a group of designers and get further insights. The aim of “3D modeling game design” workshop was to imagine alternative 3D modeling environments in which users have to achieve forms. It was thought that participants’ ideas and approach can contribute to the design process. The game framing was expected to be more enabling for the workshop participants when it comes to introducing challenges to modeling software, since challenges are an integral part of games.

4.2.1 Workshop preparation and setting

The workshop included 6 participants who all have design backgrounds and have experience with 3D modeling software. The software used by participants ranged from technical drafting and modeling software to animation oriented mesh modeling software. All participants had experience with more than one modeling tool. The distribution of designers by discipline was 2 industrial designers, one architect, one graphic designer, one game artist and one interaction designer. The workshop took place in a studio room where participants sat in two tables and various materials were provided to aid them visualize their designs. Among the materials were items such as a paper board, mounted onto a piece of soft foam, sticks, a square grid rigid foam board and transparent sheets to aim the visualization of 3D objects.

Before coming to the workshop, participants were asked to e-mail an image of...
a design work that they think is “masterfully designed regarding its geometric / visual form” and that they were able to “decipher what is good in the work and see the ideas or construction relating to form”. The emphasis on “masterfully designed” sought to make participants think about the design in terms of process of design rather than end-use functionality or other criteria.

Those images were printed and used in the first section of the workshop in which participants individually designed a game. Participants were given the task to imagine game dynamics to achieve the forms in the designs they brought. So, they were encouraged to reinterpret their knowledge about the design piece they brought as game mechanics and interactive qualities. As mentioned above analyzing existing works as rule structures is implemented in the framework of shape grammars (Knight and Stiny, 2001). Yet, in this exercise the main focus was not on rules but interaction. Participants were asked to sketch and visualize their ideas about user interaction on A4 pages. After 15 minutes of time, each participant briefly explained his or her idea in turns and other participants made comments about the work.

After the individual exercise a brief presentation of thesis topic was made. Participants, now in groups, were asked to design a “3d modeling game where users have to achieve forms” and where “it can be challenging for users to do stuff”. In 30 minutes two teams in two separate tables sketched and visualized their ideas using materials. Then the two teams presented their ideas to the group and received comments.

4.2.2 The workshop

First part

Participants were asked to think of games to recreate the design pieces they have brought. They showed certain preferences in deciding what to keep from the original piece and what to define as variables. Below, a few examples are mentioned.

Behrooz, an architect who brought the picture of the Sydney Opera House, stated that the pieces of Sydney opera house are all derived from a sphere and proposed a game focusing on that aspect of design.

“There is a story behind this, that all of these arcs, they are extracted from a
complete sphere and they are representing each continent. There are a lot of stories about this… Maybe, I was thinking, putting in a game context, we have a whole sphere and point somewhere and it divides from there, and it gives us random shapes, we can play with them and come up with new results. While I was doing this I also had that playfulness issue in my mind… You know this pottery thing, this spinning thing… Maybe we can add it to the subject and have a sphere that rotates and you can slice it while it is rotating…” (Behrooz)

Once the principle that all arcs are a part of complete sphere is established, different random or hand sliced pieces can be tried out, emphasizing the distinction between what is essential to design and what can be left to play. Although he mentioned playful interaction qualities of his mechanics, his example was game-like considering its limitation of work elements, arcs from a single sphere.

A second example was Simeon’s design. Similar to Behrooz, he also did not have an empty workspace but some kind of shape which he modified by using random variables and play elements.

“It is a head of a woman but it is actually a robot kind of mixture between woman and a man. And what you get is you have some kind of audio track of music that generates different levels of music like in different frequencies, let’s say from 20 hz to 20k hz whatever. And that kind of difference in frequencies in variables generates that extrude the polygons of the model. And what I started here was the idea that you kind of control the real character that runs around the polygons and that shapes, that actually keeps the polygons where you ran through flat. … ” (Simeon)

The final example is Alex who took one of his old game environment project. He imagined an environment with an empty canvas, but with some physics mechanics. This enabled him to generate a game level by using the same interaction and physical constraints of the game-play. He proposed using buttons for creating certain types of elements in the game level, like leaves and mushrooms.

“I start with a base what would you do as a small character and I thought over time if you keep a button pressed, the longer you keep it pressed, I am thinking it in terms of a console let’s say… You keep it pressed and it creates this shape
under you, and depending on which button you press, let’s say you have a button for square, triangle or circle it keeps making that shape flat for a period of time … ” (Alex)

Second part
The two teams created two different modeling environments for 3D modeling. In contrast to first part, there was no predefined design work to be achieved. Yet, participants still had to work with the theme achievement and playful interaction. First group, inspired by pop-up menus and history options in 3D modeling, designed an environment where you could “stop the history and draw a pipe” opposed to a linear flow of work.

“You know this history being a list graph, than history becomes this nod graph. You can turn the graph on and off or you can shake it up and get random connections, you can be very meticulous and specific or you can kind of… But that way somebody can look at how you made this whole thing and they can turn on and off other sections and see other possibilities that might have been…” (Group1)

Their presentation evoked some other ideas among participants.

“What if you are able to feed the loft not only to a shape but a 3d model like a complex shape you already built but you can fox that around it” (Simeon)

“It is kind of like wiring a circuit board and testing it with little parts of the circuit… without being afraid of burning it.” (Alex & Simeon)
The second group did not introduce any new ludic interactions to the modeling itself, but created a second phase where the construction of the model and its durability in the physical environment was tested, like a simulation game.

“Basically the idea is like kind of game environment, presented with a certain task, let’s say you have to build an object set in a certain environment like here for instance, you have a plane that is tilted and it has certain properties and your task is to build an object that can withstand that. It has like a physics engine working in the back so once you build it, you can test it out if it collapses or not and the objects are actually material based…

To give it a more game feel once you start placing objects there are actually tiny people going there and start building things, while you are actually modeling it, something else is happening on the screen. So, it is not just like your basic modeling software, other thing happen in the environment as well…

At the end once they made it they go into kind of …, they observe and you can hit the big play button” (Group 2)
4.2.3 Conclusion

Environment
Participants did not always think of the modeling environment as an empty canvas, but envisioned initial elements such as a sphere to create arcs from or a portrait to modify. The environment was not empty also in a game sense; since it had certain physics and an element of time, such as taking time for the construction to build.

Automation & Randomness
In the first part of the workshops most participants automated their tasks once they distinguished between what is essential to design and what can be left to chance. It can be said that participants produced some kind of knowledge by reflecting on the design works they have chosen. After identifying what is essential, it was common to introduce random commands such as dividing a sphere randomly or extruding the polygons of a model based on audio data. In the second part, first group who had created the nod graph also made use of random commands, but with more unexpected results in comparison to the examples from the first part of the workshop, since not only quantitative data but also functions were randomly determined in their idea.

The intention of the workshop was to encourage participants imagine situations that demand care and effort. Yet, in many cases participants decreased the effort needed by automating or randomizing the tasks. As mentioned earlier
decreasing the amount of manual work by using higher-level variables characterizes generative or parametric modeling. Participants imagined similar modes of interaction when coming up with game ideas. This preference informed the future design decisions.

**Embodiment**

In 3D modeling software, the user's representation within the screen itself is minimal, mainly by way of the mouse cursor and is not constrained. In some of the ideas participants used avatars in first person or third person view rather than a mouse and became subject to the environment mechanics.

**Inclusion of indicative elements**

In game environments it is possible to find elements in the environment that are not directly related with game mechanics but have expressive qualities, indicating the current state to the player or enriching the environment. Those include birds flying in the air, people walking on the street, etc. Second group also used such elements like idle people in addition to the ones constructing the model.
4.3 Second stage: Early design and initial prototyping

Design concept

One of the initial designs mentioned in 4.1.1, “forcefields”, has been selected for further development (later renamed as “kfields”). A reason for selecting this idea over others was that it clearly emphasized the aspect of indirect manipulation, since the only way to change the curves and lines was through external elements.

This decision was also motivated by the conclusions from the previous workshop. In the workshop it was common for participants to decrease the effort needed once they distinguished the relations between elements of design as game mechanics. Design concept “kfields” aimed to enable users set up such parametric relations between entities. Users were able to manipulate a set of geometry by creating fields that are influenced by manipulator elements. So, it was possible to create physical mechanics that control many entities and decrease the amount of manual work to change each entity. This was also related to the unexpected behavior of mechanics. It was common for participants in the earlier workshop to introduce random and automated tasks once the essential mechanics of design are defined. Design concept did not involve any random functions but it was thought that the universal behavior of manipulating fields could give results to the user that were unexpected and could yield into “unintended consequences”.

Secondly, participants at some situations thought modeling environment with some physics rather than an empty canvas. Design concept “kfields” also involved universal physics that controlled the whole modeling space. Finally, participants at some cases imagined modeling space as an environment with elements which indicate the activities going on. At this stage, there were some indicative elements that were not functional but were still included in the modeling space and indirect control was carried out by elements in the modeling space rather than in another window.

Manipulating a set of objects by using point or line elements is not novel. As mentioned earlier, in modeling elements such as attractors and repellers are used to modify a set of geometry depending on the distance they are situated from the element. Yet, their use is mostly restricted to generative modeling, which is accepted as a different category for many users. There are several reasons for that. Firstly, in generative modeling users have to construct their model and set
up relations to use them, mostly by programing. Their advantage is most obvious when they are used to control a grid of objects and they are mostly used to use to create fields of gradual change. For this prototype the aim was to stay away from this use and get feedback on their use that is more oriented towards less intricate geometries.

A conflict between the intention of designer and the universal effect of manipulation elements was anticipated, since manipulation elements do not only modify individual curves but the whole landscape of modeling environment. In this sense it brings both the convenience of modifying many curves at once but also unexpected changes in curves. The expectation was that the convenience of being able to manipulate more than a single curve with manipulation elements in the environment can increase the chance of acceptance by designers. Keeping those aspects in mind, a working prototype was designed. To make a quick prototype, only a part of this idea, manipulating spline curves and dependent surfaces, was implemented in the prototype.

**4.3.1 The prototype**

An available free-form 3D modeling program and its generative modeling extension\(^5\) were used to make a prototype of an environment in which users were able to manipulate the pre-made geometry in the environment. In contrast to typical attractor points those elements were represented as 3D shapes and users could scale (changing both the magnitude and visual appearance of the manipulation element), move, delete and copy the manipulation elements. So they were able to interact with those objects as they did with 3D models in the program that is used for prototyping. Designing those elements as 3D shapes proved to be useful for getting new insights from participants.

Due to prototyping limitations users were unable to add new curves or surfaces; they were also unable to change the relationships between entities. In addition to manipulative elements there were elements oriented towards

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\(^5\) Rhinoceros 3D is a nurbs (non-uniform basis spline) modeling program and grasshopper is its generative modeling plug-in. The reason for choosing this software for prototyping was its vector based logic and relatively easy extendibility for prototyping purposes. At the moment it is also a widely used program among industrial designers.
analyses such as the indicator element and indicator curves, which showed the effect of manipulation elements in their plane that was oriented in three-dimensional space. Those objects were also moveable, rotatable and scalable.

Two scenes were prepared for the prototype. The first scene included just a few manipulation elements and a surface that was provided in the environment. The aim of the first scene was to give a sense of the environment to users and let them experience with the manipulator elements. After this, users moved on to the second scene. This scene was more complex; it had two layers of manipulation elements which did not influence each other. The curves and surfaces in the scene were components of a chair which users could manipulate with the help of force elements and some end points.

4.3.2 Testing sessions

The prototype was tested individually with four people. The participants included one industrial designer working in a company, two industrial design students (one also an intern) and one maker space organizer. All participants had some experience with the software, so it was not necessary to show the basic controls. The participants were shortly introduced to system elements and were then allowed to use the two different scenes. Their engagement with the prototype was screen-recorded and participants were encouraged to think out loud during the session. After this part, open ended interviews were conducted to get the participants’ feedback. Before proceeding further into results, please go to <http://www.brssrm.com/forcefields/> to watch excerpts from the screen recordings.
Participants expressed satisfaction with controlling the 3D model with elements as opposed to individually controlling curves. The convenience and coherency brought by control through external element was expressed by participants.

“…visual feedback how the surfaces is actually looking, so I don’t have to rebuild and try it and try and rebuild, change the curves a little bit and rebuild that and have a look at it. I mean you get instant feedback that is very nice I think with this.. but, I mean it is also very useful to, if you look at it from a more parametric point of view how to change shapes, like when I move this leg for instance of the chair it could do this very precise and it is coming along very nicely, that is a very useful feature how to let's say I want my legs to be 5 centimeters longer or don’t have to rebuild them, I just have to move points…” (Johan)

“… Normally you have to spend more effort to change a surfaces shape, like lots of commands, but here you change the shape of a much bigger thing by adjusting the position and magnitude of very basic things…” (Bilge)

“…Actually it is good if you are not making something very specific, if you are working on surfaces, it is a much better solution. Because for that (manually controlling the curves), every control point you add makes the form more complicated and as it gets more complicated it tends to be more awkward… This can be possible maybe, we will make a new product, we can make the surfaces with this and then proceed into fine details…” (Berker)

Participants showed great divergence in tinkering with the scenes; at some instances they made major changes like greatly increasing the size of one element, while at some instances the changes were incremental and foreseeable. Concerns about loss of control and unexpected behavior were raised. One participant deleted all manipulation elements in first scene but one, to understand the isolated effect of one manipulation element.

“…I found it really frustrating when working with curves, because I couldn’t understand how curves moved, maybe because I have not used (the program) for some time…it makes sense to use its effect rather than moving curves on a plane surface. But for a thing I perceive as curves it is not as nice I think; was a
bit frustrating not being able to understand…” (Bilge)

“…Like I push down this, I change this size or I get a nice bend here but I
don’t want the bottom of this bend to be right here I want this to be like 5 mms
lower or I want to intersect geometry down here, I want to snap to that
graph for instance. So, how could I do that, can I type in a relation there or
could I just mean, I mean I am just thinking out loud. So, I guess it depends on
what kind of business you are in, we are modeling things which, things that are
meant to be produced so that is why you really have to be on top of things and
be very precise about modeling so…” (Johan)

“…I can only distinguish things when I give attention, it is not really intuitive.
One needs to think before every move about what will come out when
something is done …” (Berker)

**Representation and control of manipulation elements**

One aim of the design was to make the manipulation elements or indicator
curves represent some qualities in design. Participants were asked if they find
those elements meaningful beside their manipulative functions. Participants’
reactions varied, but they were more interested in visualizing the effect of
manipulation elements on particular entities rather than the whole area.

“…. I was also thinking about those manipulators maybe you could, maybe that
is complicated. But you could, when you have surfaces you can turn on
curvature graph, and then you can change the size of the curvature graph right?
So, something similar, like force field on these geometries would be kind of
interesting. To get a visual representation of what exactly, what the force field
actually producing and how it effects these surfaces, I mean you can of course,
now you can change the size of this ball but the force field, this ball is effecting
this surfaces is not very visual, right…” (Johan)

“….makes sense to see how it effects every time I change it, maybe it can be a
multilevel grid…but still I would not use them in a presentation, I think they
can be most helpful when modeling…” (Bilge)

“….Maybe like magnetic fields, to show how it influences the model. I am
thinking maybe you have the model in dark color and this as a light grid,
showing how it is bent, it can enhance the flow of surfaces…” (Berker)
In the prototype the influence of elements was based on their mass and their center of gravity. Yet, as it was possible in the program, participants could non-uniformly scale the force elements. Although it made no difference for the prototype, some participants proposed that it can be useful to adjust the x, y and z magnitudes of the elements separately by scaling in one dimension at a time.

In addition to changing the x, y and z magnitudes of the elements, one participant asked if it is possible to work with complex objects. One participant also commented on the different looks of attractor and repeller elements and thought they referred to different functionalities.

“What about complex objects? What is the technology behind it? Cause I am imagining something, almost like a field or gravity field which would be, say that you have made a tube or something it will still have a gravitational field different from just a simple geometry…” (Davey)

“This one (attractor element) has more surfaces, it should modify more in the direction of its surfaces, if it becomes narrow here it should modify things more in this direction, that was my expectation…” (Bilge)

**Viewports and control**

Each scene contained four viewports (top, front, right and perspective views). However, the first action the participants took was to switch to a single perspective view which took up the whole screen. They explained that this had mostly to do with seeing the direct influence of the tools on the geometry. In some cases users switched back to using the original four viewports saying that it was easier to move the elements more precisely this way than in the perspective view.
4.3.4 Conclusion

The prototype managed to pique the interest of the participants. This was mostly related to the responsiveness of the geometry; participants were able to modify the geometry by using simple elements positioned in modeling space. Participants expressed the benefit of using control elements mostly in relation to easy editing and form experimentation. They also perceived the direct feedback of the prototype as a good feature.

At the same time, the prototype was partial since it did not enable adding curves and participants were limited to manipulating the existing chair model. In this regard, participants had less chance to create a self-determined challenge and get in conflict with the software. Still, they expressed that they could not foresee the changes the force elements could cause every time they were adjusted, and were surprised by the way the scenes behaved in response to their changes.
4.4 Third stage: Prototype in the field and self-documentation

For this stage of the project, the aim was to test the design concept in settings where the possible tension between the user’s intention and prototype mechanics could be explored. As mentioned, the previous prototype had a limited ability to gather such situated information, since users were not able to add new elements but could only modify the pre-made test environment. Yet, more importantly the short and controlled prototyping session did not facilitate such an engagement with the prototype. To address those issues, a second prototype, now named “kfields”, was made that was stable enough to be left to the users’ disposal and that could be integrated into their workflow. The prototype was coded as a plug-in of a 3D modeling program Rhinoceros, which participants commonly referred as “rhino”. 15 3D modeling software users, mostly industrial designers, have been contacted for this stage of the project, although the participation rate turned out to be lower; 6 of the participants sent their diaries back. Participants have been referred by their first names unless they wanted to remain anonymous; in this case they were assigned a letter. All of the participants had previous experience with the Rhinoceros modeling environment the prototype had been programmed for, so that they could concentrate on the distinct features of the prototype. The prototype and supporting material was downloaded by the participants. After participants sent their diaries back, interviews were held remotely to get more information about material.

4.4.1 The prototype

(Before proceeding please visit <http://www.brssrm.com/kfields/> to watch a demonstration of the prototype) This prototype was in many ways similar to the earlier prototype. Users were able modify 3D elements by using the manipulation elements in the environment. Yet, now they had to create those elements in the environment, which is initially an empty three dimensional Cartesian space. Some insights from the earlier prototyping sessions were used to design the prototype for this stage. In the earlier prototype many users assumed that modifying a manipulation element non-uniformly would change its effect accordingly. This function was supported in this prototype; users were able to stretch the manipulation elements in x/y/z axis and make them modify the curves they have created non-uniformly in those axis. Interviews from the earlier prototyping showed that the shape of the manipulation elements were
critical for some users. This was thought to be relevant since one of the innovative features of this idea was to use 3D shapes instead of points as manipulation elements. To learn about users’ understanding on the shape of manipulation elements, a function was implemented that enabled users to define their own shapes to be used as manipulation elements. A user could declare any surface in the modeling environment as a manipulation element to modify the curves. An introductory manual that informed the users about the commands and functions was included in the package (see Appendix A).

### 4.4.2 The diary

Along with the prototype and the manual, a diary was included in the package (see Appendix B). This was simply a text editor document that enabled participants to embed captured images and write comments. The diary attempted to capture the important “moments” while using the prototype. A number of possible moments were listed in the diary, in which participants could put their images and comment on them. Those were descriptions such as “Register a moment which made you say It was hard to model my idea with kfields but I am pleased with the result” or “Register a moment which made you say I changed my direction about the form / idea I am modeling”.

Most of the moment definitions were inspired by the background of the thesis such as the concept of achievement, loss of control, static intention and change of direction. The main aim was to capture the moments in which participants experienced a turning point for their design, satisfaction or frustration. They were also moments where participants could fill in their suggestions for possible functions. Some moments were created to capture participants’ choices such as the shapes they used as manipulation elements. Additionally, participants were able to create their own definitions for the moments. It had been expected that this list of moments could facilitate reflection on the experience, so documenting a user’s interaction without any interruption was not the aim.

### 4.4.3 The results

Diaries were collected from participants after a period of time – ranging from 5 days to two weeks depending on the schedule of the participant. Not all diaries were in original format. Some participants simply created new documents or attached list of images in e-mail and avoided all moment definitions. One participant on the other hand regarded moment definitions in the diary as
questions and tried to answer each.

Feedback was varied in complexity and detail. While some registrations in diaries were pointing to basic controls some were related to a specific model and how it was modified. Some participants reported that the limited set of functions in the prototype prevented modeling complex objects. At those moments, participants offered functions, which they imagined as possible extensions to the application. Those functions were illustrated in the diary by using entities in the modeling space. One important aim of the prototype was to get participants’ feedback on indirect manipulation of elements. This happened mostly during interviews, when participants explained their thoughts about control in the prototype and explorative form-finding.

**Form-finding**

Participants generally stated that the prototype was a good tool for studying form. One quality that was mentioned was the easy manipulation of the modeled objects. On the other hand, some difficulties were also addressed.

“Firstly, it would be much better if it had a toolbar. Also, I got a bit stuck since we could not decide on which objects move the elements. I think that it is a very good tool for form-finding. But because of the reasons it did not enable very experimental stuff.” (Participant L)

“After all plug-in offers you endless possibilities, and you can pick one of them. It is like rhino is becoming your assistant, it does not design exactly but offers possibilities and you pick.” (Anıl)

“It can also be useful for architects and city planners. That is why I had made tall boxes like buildings…It can be good to find a building form suitable for its surroundings.” (Kezban)
I really loved the form-investigation idea of kfields. Here by moving my push object up/down I could decide on the form and the depth of my bowl. It was a great experience. Plus choosing Sphere as push/pull object was the best option.

Copying one of the environmental elements instantly changes the form of the surface created by kcurves with record history command. Seems useful for animation.

The main use I found at first thought was graphic design (sorry!) I am kCurves and mechanics to draw fluid planar curves and to edit them easily later.

**FIGURE 21.** Milad’s bowl and his comment.

**FIGURE 22.** A participant mentioned that the tool can be a used for animation.

**FIGURE 23.** Emre’s registration for form-finding. Experimenting with one kPull and one kPush element.
Predictability and precision

An aim of the design work was to provide unexpected response to the user and leave space for exploration. One participant mentioned that he was not able to control the curves precisely. He also stated that the program takes too much command and behaves unpredictable. Yet, participants also saw benefits of not being able to directly individually control curves.

“It would be really effective if I could join the curves and then play with the form by using the balls (referring to the manipulative element)… It is a bit like the program is making the design for you, but it is ok. You can easily create the curves that would end up in the forms you like.” (Anıl)

“I use f10 (control points for modifying curves) quite a lot, but I distort the continuity of curve while doing it. I liked the continuity in indirect manipulation. But I should be able to set dimensions, or I should be able guess where the curve will end up.” (Anıl)

“I can’t think of a single occasion where the end result could be planned beforehand unless you have some sort of embedded physics engine in your brain. On the other hand this is exactly what Rhino needs.” (Emre)

“I think it creates a cleaner surface when compared to the built-in commands of rhino. It does not stretch the form too much and distort its smoothness.” (Kezban)
“It is too much surprise, it should be more conscious, it is leaving my work to rhino, and the curve explodes, it becomes something bizarre.” (Anıl)

Yet, another participant stated that he can foresee the changes and use the tool to explore the form he had in mind.

“Well, Actually I see it as an analysis tool… I mean it helps me to analysis what I have in mind… analyzing by trying and seeing the possibilities” (Milad)

He also mentioned that he is fine with the tool not being very precise but would like to have more control.

“IT (referring to control by manipulating elements) does not bother me. I like it in that way, since I am trying to see the possibilities, but maybe a little more control could be better.”(Milad)
Another participant made a distinction between what she would like to define and what she would like to explore.

“I would probably like to have those points (end points) not to be distorted at all. I would probably have dimensions that I have as reference, dimensions from one end to another and be searching the form in-between.” (Kezban)

Modifying normal curves and surfaces
The prototype enabled manipulating elements to modify only “kcurves”, the curves created by using the prototype. Yet, many participants expressed their wish of being able to convert normal curves into kcurves and manipulate them. Participants also expressed that they would like to modify any surface.

“While modeling I felt such a need: first, by using history record and normal curve-loft I created a surface. Then I wanted to use kfields for fine tuning; that is I wanted to convert the curve I had drawn as a kcurve, I don’t know why…” (Kezban)

“If you are making such a plug-in you should be able to change something you have modeled in rhino. Rhino is not like max, so the plug-in you have created reminded me of that and could make it possible.” (Zeynep)
In the prototype users were able to modify curves by using record history command and so parametrically modify surfaces as the input curves change. Yet, this function was not used by everybody. It became apparent that some participants had another understanding of modifying surfaces.

“It is like punching the surface, stretch a piece of fabric to a frame and then push a ball or a cube from above, you can see the ball or the cube when you look from below, but it is stretched at the edges... I want to be able to stretch it easily.” (Anıl)

“I had one major problem, and that’s the fact that it can only manipulate its own special set of geometry. (and when I say set, I mean the curve) This limits the potential a lot, first of all I can’t easily manipulate higher-level geometry (like a surface made from kCurves) directly, and that’s a show stopper for my flow. I guess I can use the Record History function for this, but it’s not essential in my workflow. (If I’m the exception about Record History command, than ignore this first part) Then again, I would really want to apply the “k” to my existing geometry. You already implemented push and pull abilities like this. I guess this would be much harder, but even a basic FFD or Cage Box kind of functionality would be nice for 3D geometry. And even for curves, the fact that kCurves are limited (only 9 CVs max?) already limit some potential uses for me. The first thing I thought I would do was to model a vacuum packaging surface for my phone case design, using the case a pull element and using a network of kCurves to build the surface later. I couldn’t because (1), I really want to manipulate a surface directly, instead of a gazillion curves, and (2) even if I did want to use
curves, 9 flex points would not be enough. So long story short, let me use my own geometry” (Emre, written under the definition “At this moment it is really frustrating to work with kfields because of THIS.”)

**Control elements**

In the previous prototype, participants had showed sensitivity towards shape and influence of modifying elements. In this prototype some participants registered that they declared objects for experimenting. One participant stated that he had other expectations from declaring objects as manipulation elements.

“Yes, I have used other shapes, I was expecting a cube to push the curves more cornered.” (Anıl)

**FIGURE 29.** Emre’s registration for declaring own pull element.

**FIGURE 30.** Kezban’s registration for declaring own kPull element. (The big surface in the scene)
**Layers**

One function provided in the prototype was the ability to create multiple fields by placing the elements in different layers. Yet, this option was not used by participants. In interviews, some participants indicated that it was not how they imagine layers. It was expressed that they would like to assign relations by selecting individual elements rather than using the whole layer. One participant solved this by converting each kCurve into a non-interactive curve once he modified them.

“My biggest problem was distorting one curve, while trying to modify another, I guess for this you created a command called like “neutralize”; it turns it into a normal curve… I used that, but after some point it just becomes too laborious to use it on every curve that I drew… I should be able to choose that (if elements will modify more than one curve), modify all of them or just one, or three of them? It would give me more freedom… I don’t use layers if there are not many pieces, not at all at the beginning of modeling; it is like a waste of time.” (Anıl)

“I think you don’t necessarily need to modify all at the same time to achieve visual coherency. It can be implemented, like modifying the curves evenly. But, you need to be more experienced with the tool… You need to think beforehand which pieces will display a visual coherency and then set the layers…It should be up to user to determine which k element will modify another element, but the effect of elements should be determined by the program itself.” (Participant L)

**Functional extensions**

At some points participants pointed out to what they regard as functional limitations and offered extensions to functionality. Besides earlier mentioned comments about modifying normal curves and surfaces, participants expressed that inability to join curves prevented them, build what they have in mind.

“First, I wanted to remodel a previous product, I had to give up when joining the curves failed.” (Anıl)
Participants were generally positive towards the ability of the prototype to easily edit geometries. In some cases participants reformulated their role as “picking up” from possibilities or “analyzing” rather than modeling.

Indirect control was also well received. This was related to the continuity achieved through indirect manipulation. In this sense “kfields” worked similar to Bézier curves that control the spline curve indirectly, yet continuously. One design goal in using manipulator elements was to modify multiple curves and enable user to form groups of elements. This was achieved in some cases, where users modified a group of objects such as in the examples of bowl and vase above. At the same time concerns about loss of control were expressed both regarding the manipulation of single curves, because of unpredictable behavior and the manipulation of multiple curves, because of not being able to assign curves to manipulator elements.

**Thinking in advance and modifying**

One aim in developing the prototype was to facilitate form-finding by universal settings, which was expected to be both convenient and challenging. Even though participants pointed out to the qualities of prototype that enabled easy modification, they were less enthusiastic about the challenges of using universal control. This was most visible in the comments about layers. Instead of layers—
in which kPull, kPush elements modify all of the curves in their layers – some participants preferred to assign elements individually to curves. One participant mentioned that thinking in layers would require thinking the geometry beforehand and experience with the tool.

The same aspect can also be related to the comments about modifying existing geometries. Participants pointed out that they would like to modify existing geometries rather than rebuilding them as kCurves. One participant indicated that she would like to use it for “fine-tuning” the existing geometry, a use that has not been intended at first place.

Completeness and engagement

In some cases participants pointed out that their engagement was interrupted because of the lack of functionality, such as not being able to join curves or not being able to modify surfaces. This was not the aim since a design goal, as described in section 4.1, was to facilitate challenges which would result in reflections where users reconsider their approach rather than thinking that the tool is insufficient. It can be said that the limited functionality of prototype prevented such an engagement at some moments.

At the same time, in some cases, what was pointed out as functional limitation by the participant was a design decision. For example, a participant wrote “the ball modifies all the curves. It should only modify the curves I select.” Modifying all the curves in layer was a design decision but some participants regarded it as a functional limitation.

Association with specific functions and forms

Participants at some cases expressed specific uses such as animation or form-finding for a specific location (as in the example of a building) or form-finding for a logo. In addition to these, one participant associated the mechanics of the prototype with a specific designer (Ross Lovegrove) because of “surface continuity” and “softness in transitions”. Functional qualities also played a role; a participant associated the prototype with “bowl and basket like forms”, “forms with wings”, which are “U shaped forms with angles”. Also two registrations demonstrated bowl and vase shapes that have wing like side surfaces. In the prototype participants could make curves with fixed points at the end and were unable to join them continuously, so ‘U’ shaped forms can be related to this functional limitation.
5 DISCUSSION

5.1 Control and digital material

At this point it is useful to interpret the two terms that were introduced in the background chapter, “workmanship of risk” and “workmanship of certainty”, in the light of the design process. An important point to consider is how the concept of risk and certainty is defined in relation to user’s intention. It is possible to define the criterion for certainty as a loyal implementation of what user intends to model. In this case, a modeling application which makes the precise execution of intention challenging involves risks. Yet, from another point of view, what is planned does not need to be accepted as a given but it can be said user’s intention is partially defined and user’s judgment already involves risks. Further, it can be argued that modeling application with its mechanics ensures quality and decreases the risk. In this case, it is not the implementation of a plan but the mechanics of software that sets the criterion for certainty. The approach in this thesis was in that direction and it has been assumed that the intention of use is not fixed and can be negotiated. 3D modeling in this case is not only a registration of ideas or a dialogue with representation but also involves reflection through modeling material. The tension between the intention of user and the behavior of material facilitate shaping and reconsidering initial design and form. Although participants did not register big shifts in their design while using the last prototype, this tension has been touched upon in the level of control.

In the interviews participants stated that prototype they were using did not enable precise manipulation of elements and registered moments in which the response from program was unexpected. At the same time, it has been mentioned that exactly because of not being able to control the elements directly it was easier to achieve continuous curves, since indirect manipulation decreased the risk of distorting the curve. This is an interesting aspect since the element of risk was caused because of the precise control for creating curves. In this case the source of risk seems to be judgment rather than dexterity and indirect manipulation enabled participants to use less judgment and thus decreased the risk. Exact control and curve quality in such cases seem to be contrary and handing over some of the judgment to computer was identified as a good quality by some participants. So the tension between process and intention mentioned earlier can also be viewed as the tension between user’s judgment and the behavior of material. I think this is also how concepts
conflict and challenge can be defined in the context of this project.

In contrast to dedicated form-finding application which is both programmed by the same designer or team, kfields was not task specific. Participants did not set the mechanics and relations between elements themselves. It was a given in the program, i.e. users were not able to change how the geometry behaved in response to manipulative elements. Conflicts experienced by participants, like trying to precisely modify curves, emerged partly due to this setting. An important difference between a task specific form-finding application designed with an intention in mind and an application that is a given in the design process is user’s engagement. When the application or programming sketch is also developed by the same team that uses it, it is possible to go back to the mechanics and change them. This was not possible for participants when using the prototypes. This difference can also be mapped to the distinction between material and structure mentioned earlier. Mechanics designed by the same designer, who uses it, is perhaps more like a structure while mechanics that are a given in the process is more like material.

This also shows that “high-level” control of geometry does not necessarily match users’ intention. In the prototyping sessions users expressed the need to be “on top of things” or the concern about leaving the design work to program. In some cases participants referred to the outcome of the program by using third person phrases such as “it does not stretch the form”. In those cases, high-level manipulation was not a precise instrument of the user for automating tasks but users got unintended replies.

Participants’ feedback also point out to in what conditions can the loss of control be tolerated. Continuity of curves was one subject participants were willing to hand-over control to program mechanics. Yet, some cases were perceived as functional limitations and participants pointed out what they felt missing. Examples are being unable to join curves and assign manipulator elements to curves. Regarding participants’ feedback, loss of control in those moments was quite different from loss of control when it comes to modifying the curves based on mechanics.

5.2 Interpersonal use

Participants used the prototypes in ways I did not expect during the design
process. Especially at the second stage, during the prototyping session participants modified the pre-made environment quite unexpectedly, by making big changes in manipulating elements.

This brings in an interesting aspect of being able to modify the geometry with a few basic elements. One focus in the project was the tension between the intention of designer and the behavior of the software. Yet, another interesting aspect to consider can be the different intentions of different designers about design work in a collaborative setting. It is possible to say that in kfields, when handing over a design, designer also hands over an interface to the design. That was what happened at the second stage of prototyping, when participants modified a pre-made model much more boldly than I had personally modified before carrying out the sessions. It was also unexpected for me that participants scaled the manipulative elements non-uniformly, something I have not thought before. Curiously, participants did not register such uses in the third stage in which they build the model rather than just modifying it. Although non-uniform scaling was functionally enabled, manipulative elements were uniform in all registrations. It was other concerns that were registered such as controlling curves and manipulating surfaces. Different activities such as constructing or modifying the model addressed to different concerns at those stages, an example of how intentions can differ for different activities.

At the second stage, one participant mentioned that it would be interesting to work in a template in which manipulative elements are fixed and user can only work with curves. This also suggests other possibilities such as creating a workflow in which one user creates a template model with all relations but it is up to other users to modify the scene.

5.3 Platform

The final prototype in the design process was platform dependent, e.g. it was built for a specific CAD tool. This decision was based on several reasons. Firstly, CAD programs are extensive; they are the result of many years of development effort. Building a CAD program from scratch is hardly possible in the scope of a short project. Secondly, users of CAD programs might not always have the opportunity to download a new program. The prototype delivered in the final stage was tiny and did not need to be installed. One participant mentioned that the computer she works with at her workplace
needs IT support “even to install a typeface”. That is also the case for many computer rooms in higher education. Designers and design students are not always able to install a software tool they wish.

At the same time, using a platform has drawbacks such as dependency on a propriety software or incompatibility issues. The latter aspect limited the number of participants in different phases of the project. For example, a participant failed to get the plug-in working in her computer at work since it was not the latest service pack. She also stated that she was unable to upgrade her software, since in the office they have agreed to use the same version in every computer to avoid problems.

Beyond these practical concerns, platform influences how the functions of the application are understood by users. In the final prototype, the strategy was to create parallel commands of the original platform such as kPull, kCurve, kHide. Those commands were interactive only among themselves. For example, kPull elements did not modify any normal curve or surface created with the original commands of the program but only kCurve elements. This was not the expectation of all participants since they have mentioned that they have tried using kPull elements on a surface but it “didn’t work”. In another case participants aimed to “join” kCurves but failed, the function was not supported. For participants there was no clear distinction between functions of the prototype and the platform software. Participants tried to combine the functions of both.

This expectation points out to the question of how such functions can coexist with modeling in traditional ways. Many participants expressed that they would like to modify their existing geometries or be able to assign manipulative elements to any curve in the modeling space. At one case this was related to “fine-tuning” existing geometry, pushing the form-finding function into the background. Similarly one participant registered that he turned interactive kCurves into normal spline curves when he realized that he was “distorting one curve, while trying to modify another”. In those cases concurrent use with traditional methods of modeling enable users to circumvent the mechanics of the program. We can say that it provides more choices, but also decreases the conflict that might be experienced. Engagement also becomes less game-like when users are able to circumvent program mechanics and avoid the challenging quality of digital material.
5.4 Further design ideas

This section is about further ideas design process inspired. Surely, the prototypes participants tried out were incomplete and lacked some obvious functions, such as joining curves. Here, the aim is not to illustrate a complete system solution, but some extensions that particularly address the potential of kfields.

Arcs and straight lines

One feature that has been appreciated by participants was the interactive modification of curves. The prototype of kfields focused on spline curves, but this can be extended to lines that are geometrically simpler. For example, in the figure below first row shows how a line with an arc segment is created in a traditional trim and join method – both curves are first trimmed and then joined. Second row shows how this can instead be realized by simulating an elastic rope.

Although it might take more effort to create the arc by using the second method it can be more rewarding in case the line is modified. Two rows are different when it comes to interaction for modification. Curve in the first row is modified by traditional control points, while the curves in the second row are controlled by interactive elements that can be scaled and moved any time. As mentioned in section 2.2, many CAD programs support “history” function that modifies dependent geometry when basic elements such as arcs and control points are modified. Yet, as one participant mentioned referring to end point of curves, it is important to keep basic elements ready to hand in the modeling space. Those basic elements can also be used in combination with pulling or pushing manipulators that are implemented in the prototype.

**Figure 32.** Comparison of two sequences of drawing a curve.
Such physics inspired manipulations are used in animation software to calculate the behavior of various materials such as hair follicles or ropes. Much work has been done on “cloth simulation”, especially for the realistic simulation of fabric wrinkles. These animation techniques also inspired contemporary generative design software and have been related to “parametricism” – the use of parametric relations to create non-rigid geometry – as a style (Schumacher, 2009). I think such simulation-like feedback can be useful even to create rigid geometries composed of arcs and straight lines due to easy manipulation they offer for sketching.

The same idea can be applied to surfaces. One participant described how he would modify a surface as “punching the surface, stretch a piece of fabric to a frame and then push a ball or a cube from above”. This can look like the image below, with surfaces that have different elasticity and plasticity values.

**Centerless manipulator objects**

Prototype kfields used centered manipulator objects, even though objects were able to take different x/ y/ z axes magnitudes and shapes, reference point of effect was still a center point. This does not be the case and linear and planar manipulator can be used that are able to manipulate objects in the axes or planes that user determines. Unlike point objects, it would be possible to change the effect of those objects by rotating them.
Modifying existing geometry

Participants expressed that they would like to modify existing geometries without using curves but did not illustrate this in detail. In animation, existing geometries are modified with the help of lattice deformers (also called box modifiers or cage boxes). Lattice deformers create a lattice box around a geometry that can be used to deform a vector or mesh geometry. This is done by pulling the points (generated in x,y,z directions) of the lattice box. The container box can always be modified and when the box is erased the geometry returns to its original shape. A similar idea can be combined with the idea of indirect manipulation in kfields, by using manipulator elements. So rather than manipulating points directly in the lattice deformer, they can be manipulated through elements.

Another type of modification that is more integrated into the mechanics of kfields would be to recreate the geometry by reverse engineering the curve and assigning points and manipulator elements. A few participants expressed that they would like to convert normal curves into kCurves, rather than redrawing it manually. One possibility can be to carry out this conversion by computation. As mentioned in chapter 2, hand drawn lines can be turned into basis splines by gesture recognition and optimization. A similar idea can be to create kCurves from other geometry. Yet this time it is not control points but manipulator elements that are created. The difference in comparison to a lattice deformer is the more detailed control of geometry with end points and manipulator elements.
The interesting aspect of this conversion is the creation of manipulative elements based on the geometry, so the conversion is not only about manipulating the geometry with elements, but rather calculating how it could have been constructed. This can be an option if the dimensions of the target geometry cannot change because of dimension constraints or because it is optimized by some other means. Converting an existing geometry also provides user with elements he or she can modify at the beginning of the design process, rather than an empty canvas. One use of this conversion can be creating manipulative elements from a “target curve” and use the same manipulative elements to modify other curves.

A more advanced calculation can be selecting not just one curve but multiple curves and create manipulating elements that are based on those curves and that try to construct new kCurves similar to their originals. The resulting construction can also enable unexpected modifications, since the constructed relations will differ from the original intend.

**Different modes**

The prototype used in the project had a single method for calculating the
modification on curves. Yet, this does not need to be the case. In productivity software and games such options are provided as customizable interfaces, skins, templates or game-modes. These options change different aspects of software, for example skins have no effect on functionality but change the appearance of interface or game elements while different templates provide different initial elements.

Similar ideas can be adapted to kfields, which enable users to customize the application for themselves or other users. Various “modes” can be created that are based on different variables or ratios between elements. This can be increasing or decreasing the power of manipulative elements or their area of effect. In addition, different shapes can be used to represent manipulative elements for different modes.

**Physical interaction**

Besides desktop interaction the idea can be extended into physical space. Spatial arrangement of elements, with which user modifies the model, can be represented in the physical environment. Extending interaction to physical space is especially suitable for facilitating the participation of a wider audience by means of direct input. This can also enable the concurrent use of program by many users and real-time communication of different intentions users have. Below is a sketch showing how current interaction can be represented in the space with the help of tangible elements that represent manipulator objects. These objects can be moved or adjusted.

**FIGURE 40.** Modifying the geometry through objects that represent manipulative elements.
Besides directly representing desktop interaction, other modes of manipulation can be investigated that take advantage of space in a different way. Below is an example that enables exploration of form by moving a table object in the space rather than tuning individual elements. Different forms can be explored by moving the screen mounted table. Colorful totems represent different manipulator elements.

**FIGURE 41.** Manipulation by moving the screen that represents and displays the geometry in space.
6 CONCLUSIONS

6.1 Role of interaction designer

Design effort during the process was directed towards facilitating form exploration in relation to engagement with material. A crucial aspect related to this is the role of interaction designer in supporting creative activity: It is possible to say that while establishing design ideals, interaction designer more or less acknowledges a certain view on what is integral to creative activity and what is seen as tedious work. A good example would be the distinction between dialogue with representation as creative work and interaction with computers as tedious task. Yet, if this thesis has managed to show the distinction is not undisputed, especially from the viewpoint of craft and design which acknowledge effort spent with material an integral part of creative work. At the same time it needs interaction designer's skills to create material that is found meaningful for users. Aim here is not to decrease the amount effort spent on modeling or to make it less skill-demanding but rather to make effort meaningful.

Evaluating the value of digital material as an integral piece of creative process is tightly coupled with the design and research methodology that is followed. It is a matter of emergence to understand if the material becomes a part of the creative process, and the answer is highly subjective. This necessitates methods that are able to capture this situated and qualitative nature of engagement. This has been the aim especially in the final stage of design process with a prototype left to users and with the use of self-documentation. Yet, limitations of prototype and the short time span for users to experience the prototype were still felt. Apart from functionality limitations, a participant expressed that “you need to be more experienced with the tool” to use the layer functionality in the final prototype.

6.2 Many facets of indirect manipulation

The main reason of choosing indirect manipulation was to make the execution of ideas more challenging and leave space for exploration. The challenging aspect of using kfields has been mentioned by participants, especially in the final prototype. Yet, participants during various stages of the design process also expressed that they found the use of “easy”, “time-saving” and “resulting in more continuous curves”. Indirect manipulation obviously is not solely
challenging in this case. Many advantages of parametric modeling such as easy editing or time saving once the scaffolding is done (the relationships between geometric entities established) can be mapped to the parametric manipulation in kfields. These were also regarded as attractive qualities by participants. So, although the departure point was making modeling activity more challenging for executing the form in mind, many participants found less effort demanding qualities to the prototype. So, when designing for exploration by using indirect manipulation it is useful to keep both of these aspects in mind.

The notion of demanding less effort was touched upon most straightforwardly during the modeling game design workshop. Many participants imagined modeling space not as an empty canvas but with some initial elements or mechanics that lead them to the design work they have brought with. In this sense, it required less effort to model the work. It should also be noted that, participants’ activity was in a sense retrospective since they had to create mechanics for a pre-determined result. At the same time, when initial elements or built-in mechanics are introduced in a way which is not retrospective, as in the final prototype many challenging qualities associated with mechanics were addressed. It would be wrong to say that these qualities are necessarily negative. They have the potential to conflict with the original intention of the designer in a productive way. Yet, a crucial point to consider is the distinction between indirect and impossible. In the final prototype when some participants realized that they are not able to model what they have in mind, because they were not able to join curves, they attributed this to the insufficiency of the prototype rather than reconsidering their approach, a point also made by Brenda Laurel (1986) in relation to the loss of first-person feeling.

6.3 Communicating history through material

An important aspect of materials is their role in supporting communication and affordances in design process. Jacucci and Wagner (2007) touch upon how material qualities of physical models communicate the performative actions carried out when creating them. For example residues of a model that is carved out from a board indicate the action carried out on the model, enriching what the model conveys. “These leftovers do not simply disappear (unless put into a bin), they witness some of the action that has been taken and the design decisions that motivated it.”(p.79). Such qualities also show that the history of a design work is not only about showing different stages of the work in various
time frames but also giving a sense of actions the work went through. Kfields touched upon how these performative qualities can be created in 3D modeling. For example, curves in kfields are not curves as such but are pulled or pushed by manipulative elements. Apart from providing the affordance of manipulating the model, manipulation elements indicate that curves have been subjected to different modifications. In contrast to a history list which is accessed through graphical user interface, this provided a juxtaposed view of the material quality of modeling environment, as those manipulative elements were spatially located in modeling space. Similar thoughts have been pointed out by workshop participants in section 4.2, when they proposed performative elements like workers building structures or resting after they are done with building. So, accessing history or communicating the possibility of easy-editing to the users does not need to be limited to the design of windows or menus. These can be designed in a tight connection to the control and behavior of 3D modeling material
REFERENCES


Terry, M., Mynatt, E., Nakakoji, M. and Yamamoto, Y. 2004. Variation in


WELCOME!
Thanks for participating in the project kfields. To shortly summarize kfields is a form-finding tool in which curves are manipulated indirectly and universally by means of elements in the modeling space. So, it aims to bring experimentation, surprise and consistency to your work.

INSTALLATION

To install kfields you should first copy the file kfields.rhp to some location in your computer. This can be the plug-ins folder of Rhinoceros. This folder is probably located in Program Files > Rhinoceros 4.0 > Plug-ins in your computer.

After this step you should install the plug-in. When you open Rhinoceros, in the top menu bar click Tools > Options. Under the title Rhino Options you will notice Plug-ins. After you click on the button Install, Select the kfields.rhp file in the location you have placed it.

COMMANDS

All commands in kfields start with 'k'. To see them simply write 'k' in the rhino command line.

-kCurves are the most basic elements in kfields. They have fixed start and end points. They are straight unless there is a force element that modifies them. Once you create a kCurve, two points at the start and end of the curve appear. You can later manipulate the curve by moving those points.

You can create kCurves in different flexibility values. This is simply the number of control points that will be created for the curve.

-Force elements modify kCurves. kPull elements pull the curves into their centre while kPush elements push them away from their centre. You can copy, scale or rotate the elements. The bigger an element, the stronger it is.

If you scale force elements non-uniformly you will notice that they will have different x / y / z powers.
You can also create **kSubcurves**. Those are curves that are dependent on kCurves and are erased if the parent curve is deleted or neutralized. The start and end point of kSubcurves change depending on the changes in parent kCurves.

You can later change their parent curves, or the position of kSubcurves on their parent curve.

As can be seen from the image, kCurves and kSubcurves are affected only by the force elements in their own layer.

As you have noticed kPull and kPush elements both have the same shape. This is not very helpful. You can declare a surface or a polysurface object a force element by typing **kDeclarePull** and **kDeclarePush**. This enables you to use your custom shapes as a force element.

But make sure that your declared object is not very complex as this will make the program slower.

You can hide and show all the force elements by typing **kHide** and **kShow**

As you copy your force elements or kCurves you will be creating new interactive force elements or kCurves. If you want to convert your kCurves or force elements into normal Rhino objects use **kNeutralize**.

Note: If you neutralize a kCurve its dependent kSubcurves will be automatically deleted.
You can take advantage of the Record History command. You can also use the same named button at the bottom of the rhino document, (near Snap, Ortho, Planar Options) By using this, you can make loft and revolve surfaces that respond to your force elements.

Don't forget that this is just a beta version and is unstable. Back-up your files and save your work if you are not doing simple manipulation. If something goes wrong you can try using kFieldsReset command. This command simply resets all the runtime information associated with kfields and tries to recreate the right geometry.

Also note that, when you open a rhino document the kfields geometry you have saved from a previous session will not be interactive unless you launch the plug-in. The plug-in launches automatically when you type one of the commands.

Now you are ready to use kfields! Proceed into the document myDiary!

IMPORTANT!

This plug-in and all related content are provided on an "as is" and "as available" basis. Your use of this plug-in is at your own risk. The author of the plug-in disclaims all warranties, express or implied, including without limitation warranties of merchantability, fitness for a particular purpose, and non-infringement.
APPENDIX B. THE DIARY

Thanks for taking part in the project! Your personal experience of using kfields is the most valuable feedback. As you work with kfields, you might be in situations that are worth recording. This document is a diary for you to capture important moments. Try to make no less than 5 registrations. You can also create your own headings for registering different situations. Feel free to multiply any template if you feel like!

It is best if you could:
- Try to integrate kfields into your current or any other design work. (don't forget to back up your old document first)
- Spend at least 3 hours using it over the course of a week.

Don't forget to support the situations below by capturing images. (To capture: Click the left upper corner of a Viewport in Rhino > select Capture > To clipboard and then paste the images)

mydiary

Register a moment which made you say ...

insert a screenshot or an other image to describe situation

write a few sentences to describe the situation

Register a moment which made you say I am thinking hard on how to model my design with kfields.

insert a screenshot or an other image to describe situation

write a few sentences to describe the situation

Register a moment which made you say I declared my own shapes for the kPull and kPush elements.

insert a screenshot or an other image to describe situation

write a few sentences to describe the situation

Register a moment which made you say I ended up in a design I initially did not plan to model.
Register a moment which made you say *It was hard to model my idea with kfields but I am pleased with the result.*

Register a moment which made you say *At this moment it is really frustrating to work with kfields because of THIS.*

Register a moment which made you say *I changed my direction about the form / idea I am modeling.*

Register a moment which made you say *At this moment I switch back to normal curves because of THIS.*
This section is important! I rely on the material you provide. Please keep in mind that the images and texts can appear in public and does not include any confidential information.

I use first names to refer to my participants in the thesis document. Please check the box below if you want to remain anonymous in the thesis document or in a possible future publication.

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Date