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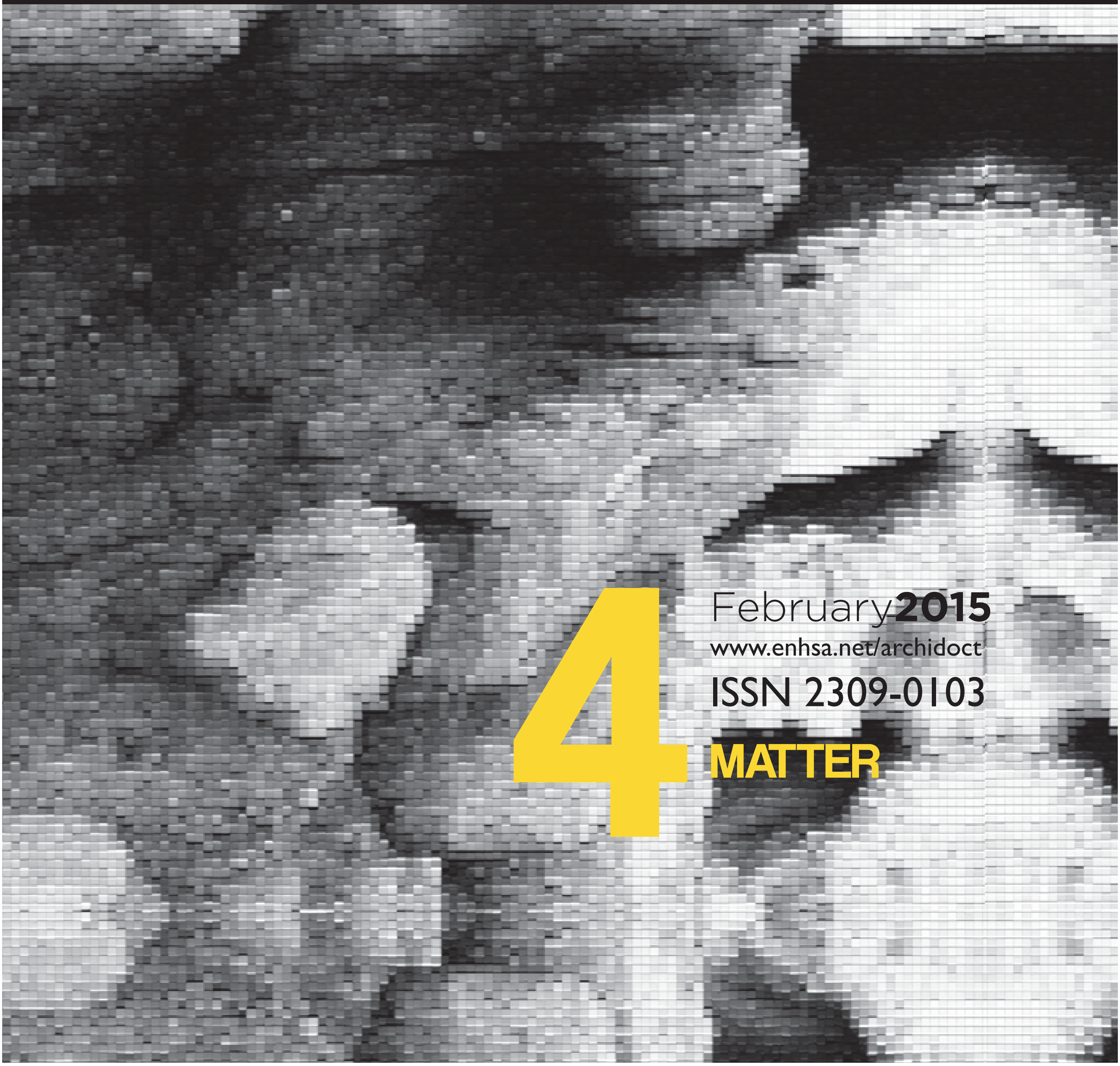

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February**2015**

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ISSN 2309-0103

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ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 2 (2) / February 2015

Material and virtuality

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Abstract

Through tangible experiments this paper discusses the dialogues between digital architectural drawing and the process of materialisation. The paper sets op the spans between *virtual and actual and control and uncertainty* making these oppositions a combined spaces where information between a digital world and a physical world can interchange. The paper suggest an approach where an overlapping of virtuality and the tangible material output from digital fabrication machines create a method of using materialisation tools as instruments to connect the reality of materials and to an exploring process.
In this paper investigations in sheet steel form a substance of concrete experiments. The experiments set up shuttling processes in between different domains. Through those processes connections and intermingling between information from digital drawing and materiality is created. The dialogues established through these experiments is both tangible and directly connected to real actions in digital drawing or material processing but also the base for theoretical contemplations of the relation between *virtual and actual and control and uncertainty*.

Keywords

Drawing; Fabrication; Virtual; Steel; Material; Processing

ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 2 (2) / February 2015

Research context

The experimental substance in paper consists of a series of experiments carried out in sheet steel. The experiments are a part of a larger mass of experiments also including concrete and wood. The combined mass of experiments form the investigating basis of the PhD project *Bespoke Fragments*. In this paper only a selected type of the steel experiments will be described in detail. However the scope of the overall project will be presented to situate the work in a correct and understandable context
The project *Bespoke Fragments* seeks to explore and utilise the space emerging between the potentials of control through digital drawing and fabrication and the field of materials and their properties and capacities. Within this span the project is situated in a shuttling between the *virtual* and the *actual*, investigating levels of *control* and *uncertainty* originating from these.

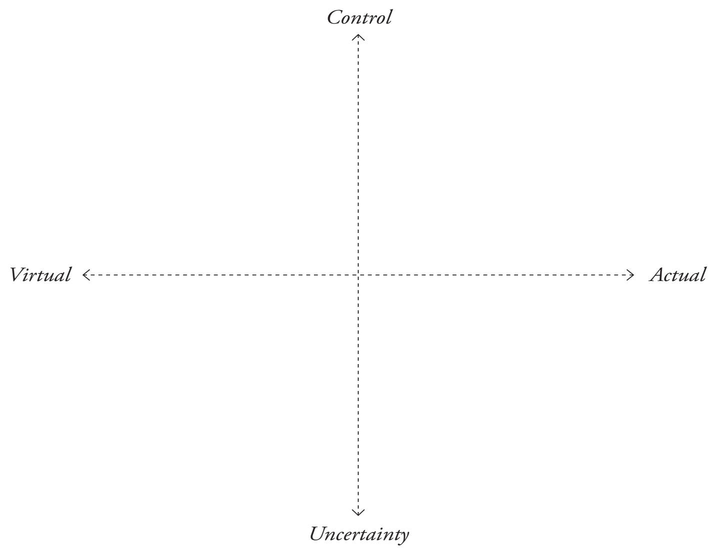

Figure 1.
The Virtual and the Actual, Control and Uncertainty. The experiments operate within this field constructed context using digital and physical tools and materials

Throughout the experiments – both the ones introduced in the paper and in the overall project – the term *fragment* plays a role in the genesis and the intended conception of both the digital and physical production. Firstly it handles the understanding of scale related to – especially – the physical artefacts. They are to be seen as 1:1 existences both in their form and their behaviour. They should be perceived directly and not be interpreted in relation to another scale. They, however, should neither be perceived as concluded objects. Rather they are to the seen as openings, preludes or *fragments* that potentially could be a part, a component or part of a component in a larger context or construction.
Through tangible experiments the project discusses materiality and digitally controlled fabrications tools as direct expansions of the architect's digital drawing and workflow. The project sees this expansion as an opportunity to connect the digital environment with the reality of materials – and use realisation and materialisation to generate architectural developments and findings through an iterative mode of thinking about the dialogue be-

ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 2 (2) / February 2015

tween drawing, materials and fabrication. Consequently the interest and mind-set behind the project and the experiments builds upon contemporary and earlier discussion about the relation between (digital) drawing and making in architecture.

"Bringing with me the conviction that architecture and the visual art were closely allied, I was soon struck by what seemed at the time the peculiar disadvantage under which architects labour, never working directly with the object of their thought, always working at it through some intervening medium, almost always the drawing, while painters and sculptors, who might spend some time on preliminary sketches and maquettes, all ended up working on the thing itself which, naturally, absorbed most of their attention and effort"

(Evans 1997).

The above quotation is from Robin Evans essay *Translation from drawing to building* from 1986. While his realisation and concern is probably still valid in almost all architectural practises the current landscape of architectural tools is indeed changing. Digital drawing and design tools have either replaced or supplemented sketching and drawing by hand. Alone however these new tools still – with Evans's words – put the architects at the disadvantage of newer working directly with the object of their thoughts. Interestingly a new set of tools seems to find the way into the architect's toolbox. In today's field of, especially, architectural academia and education – but also practise – the importance of *making, fabrication and realising* seems more and more pronounced. Many directions and opinions have already emanated. Digital fabrication tools extend beyond the computer and bring new perspectives to Evans's reflection on the relationship between *architect, drawing and building*. Working closer to the materialisation of thoughts has the possibility to be common practice for future architects. This project positions itself in continuation of Evans thoughts and tries not to situate the architect as the builder, but to bring the materials, the matter, close to where the architect is working and shaping.

Digital lines

Today's digital drawing is well implemented and used in any of the architect's processes. From the early sketching and concept development to the final construction drawings. Digital drawing is serving both as a highly controllable and flexible tool, being able to produce precise and interchangeable information.

In the recent decade a fast evolution in digital fabrication has taken place. Going from a solely code controlled environment, industrial grade digital fabrication tools such a water jets, CNC routers and industry robots can now receive programmed information originating from digital drawing. Industry grade digital fabrication machines hold the capability to process real materials with quality and precision.

Compared to lines done by hand digital lines and CAD software can create contours and surfaces so complex that one can no longer be certain of their spatial coherence (Cache, 2010 pp. 60-61). Digital lines are at the same time very well defined and very detached from actual spatial relation. Thickness of surfaces does not exist and scale is not a defined concept. They are total reproducible within their own domain and the data describing them can easily be transferred to a production context. However the difference between what they are inside a computer and what the do within a production compromising the reality of materials calls for situations where realisation is not a representation of an idea but a dialogue between virtual and actual (Cache, 1995).

The link between digital drawing and material processing bring the material existence

ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 2 (2) / February 2015

closer to the act of drawing and through that reinterprets the meaning of the drawing. While the making of the drawing can be parallel to the making of a traditional representative drawing, the content of the drawing shifts. The architect can still be in control of the lines, but where the traditional lines are representatives or notations for the outlines of formal or material borders or transitions, the lines drawn with the intention of digitally informing the fabrication becomes either direct or indirect tool paths for the actual material processing.
The possibility of a close linkage between drawing and realisation is thanked to great advancement in the field in the recent years. The combined outcome of the spread and progress of both software approaches and hardware collectively have built a very well developed domain for designing and workflows to push digital information into reality (Sheil, 2005 p. 24)

Material specificity

The project is implicating three different materials; wood, steel and concrete. Those three materials have been selected because they together form a varying range of material properties.
The wood is naturally solid with a heterogeneous material structure. The grains running through the wood are defining the material behaviours continuously. Steel is a homogeneous material that is often processed in its solid state and from standardised formats. On the contrary, concrete is mainly processed in its liquid state, offering a homogeneous matter that actively uses its mass to flow into formwork.
The range of materials is well known and all established in the world of building practice and architecture. They are often used in different dedicated situations where they perform in often repeating, standardised and well-proven ways. Despite their controlled use and refined formats they all offer inherent autonomous material properties and capacities.
Materials properties are defined as objective characteristics that can be listed. Capacities, on the other hand, are *relational.* A capacity to affect always goes with a capacity to be affected (Delanda 2007). Properties cannot be overlooked, but the relational character of capacities becomes of distinct interest since the behaviour of this project is to affect material with tools and information from the digital domain. Delanda's coining of the definition of material properties and capacities is used in the following investigations to connect actions made in the digital domain and in the material domain.

Dialogue between digital and material

The point of departure for this project is the observation of the digital drawing as an initiator for working directly in and investigating materials and material behaviour. The control of fabrication tools through precise drawing opens up a new approach to materials in an architectural context. The drawing that controls the tools becomes specific for this to happen. And the knowledge and intention behind the drawing becomes specialised through the understanding of the fabrication processes and their affect on the materials. This creates drawings that are representations not of form, but of fabrication information that embeds directly into materials (Ayres 2012). An important aspect of this operation is that the processing not only creates form from the material, but also intermingles with the material's inherent properties and capacities and through specific control creates new capacities.

ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 2 (2) / February 2015

These capacities might be affected by internal properties, external situations and/or affect situations. A dialogue between the digital domain and the material world is at the same time an alternating dialogue between control and uncertainty – specific control can lead to unpredictable behaviour. The notion of uncertainty is here parallel to David Pye's coining of the concept of workmanship of risk (Pye, 1968, pp. 20-24). Pye explains the difference between the workmanship of risk and the workmanship of certainty through comparing writing with a pen and printing. Where the result of printing is predetermined the act of pen writing involves as risk comparable to that of the creation of unique craftsmanship. The result of neither craftsmanship nor pen writing is fully controlled – predetermined – but both unveil uncertainty through a controlled direction or intention.
The drawing also becomes the carrier of the creation of material capacities. The drawing is created in a *virtual* space. *Virtual* is in this context understood as spaces of possibilities where parameters are variable and changeable and not definite or inalterable. In *virtual* space conceptual, formal and design decisions can still be made and respond to whatever situation that might exist or arise. When drawing embeds not form, but capacity, into the material through fabrication, the emergence of *virtual* space is no longer limited to the computer's digital world, but extends into the materials' world. According to Deleuze (Deleuze, 1991 pp. 96-98) *virtual* is not opposed to *real* but opposed to *actual*. *Real* is opposed to possible. For Deleuze pure possibility is not a productive condition. This Deleuzian perspective and differentiation is made operative in following experiments through the contradistinction of control and *uncertainty* where a situation of mere uncertainty is similar considered problematic. At least a fraction of intention, control and reality is needed to produce a beneficial situation. Deleuze's distinction between real and actual also makes the situations of virtuality in reality tangible.
The experiments described in this paper is interested in the type of drawing that let's the design space – the virtual space – include the materials and a possibility for decision making and exploration with the materials. This intention calls for certain ways of regarding the act of drawing. While no digital drawings – including coded and parametrical drawings - are excluded in this combining of the digital and the physical into a virtual space, it is crucial that the establishment of the digital design creates potential for investigation in the material domain and is not limited to the realisation of a definite. Seen this way, the type of digital drawing, applied in the following experiments might relate more to a classic relation between the drawing and the materialisation than more recent digital strategies – BIM for instance - regarding where design decision can be made. A classic architectural drawing set creates a direction for a realisation, but leaves many decisions to be solved through the information of the construction and materialisation. Comparable is the intention for the dialogues between the digital drawing and the materials in this explorative context. However, where a classic architectural drawing set relies on the reading, conventions and the esoteric understanding of the drawing in order to produce realisation, the digital drawing pursued in the paper talks directly to the physical world.
In these dialogues, knowledge of material behaviour, tool possibilities and concrete materialisation results directly contribute. Therefore a continuous production also becomes a constant evolution as a shuttling between the virtual and actual start to benefit from each other's specialities. Information from reality into the digital can happen through the humans facilitating both sides. Some information might be experienced based – for instance through transformation and assembly of processed element. Other might enter the domains through digital photography, measuring or digitisation through 3D laser scanning and metrology.

ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 2 (2) / February 2015

The project's intention is to investigate the relations described above. Through concrete experiments the project is developing work that in different ways positions and relates itself in the dialogues between the *virtual* and the *actual* and between *control* and *uncertainty.*

Experiment strategy

This paper specifically outlines and explains investigations made with sheet steel. The experiments were carried out with the intention of forming a workflow and a producing experience close to the material and production. Consequently even simple elements of the workflow were carried out and hands-on knowledge about the fabrication tools was gained. To understand fabrication tools conceptually and how they abstractly can blend with design processes is the first step towards an integrated practice. But without deep knowledge of both the tool, the machine and the understanding of the working relationship within the specific processes control of the technology, and hereby an opportunity of designing, is not obtained (Callicott 2001).
The construction of the experiments builds upon the idea that the appreciation and utilisation of uncertainty comes through mastering and control. To operationalise uncertain moments and events happening from the steel, a contrasting control needed to be applied. This allowed a workflow where controlled intentions, intuitive actions and openness to uncertainty could exist.

Unfolding potentials

The experiments started out as an intuitive series of not contemplated material test where different approaches to folding, stretching and bending where tried out. Deliberately almost all experiments trajectories involved an act of transformation after the processing of the steel itself.
Hereby the fabrication did not become a transfer of form from computer to material, but an embedding of capacity into the materials. The subsequent transformation at the same time gives the architect a way to re-enter the process. If transformation and assembly is not decided ahead of fabrication it leaves a design space open and allows direct interaction between design development and the processed materials. The movement from digital to material does not become an abrupt actualisation but something that happens through an elongated virtual process. This way elements of control, decision making, discovery and reconsideration is distributed throughout the whole process. The designing becomes '…a creative and experimental process that occupies the full extent of architectural production…' (Sheil 2012).
Experiments were established around a feedback-oriented workflow. A drawing was created, drawing informed fabrication tool – a water jet cutter – through CAM software, fabrication realised in steel according to drawn geometry, steel was transformed on the basis of the given capacities into a shape, shape underwent evaluation – geometry based, structural based and material behaviour based – and evaluation fed into the next drawing (Fig. 2). This workflow might seem linear but given that multiple versions and experiments happened coherently it altogether appears as a network of different events and discoveries, all informing each other continuously.
Through the workflow the experiments closed in on the material properties of the sheet steel and unfolded a number of techniques and design spaces through which material ca-

ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 2 (2) / February 2015

pacities could be developed.

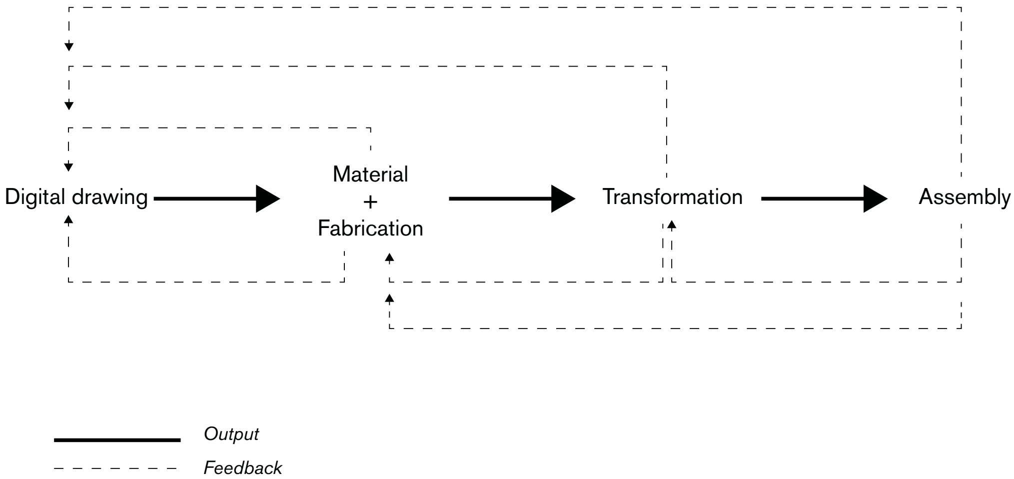

Figure 2.
A workflow based on constant feedback and output creates constant dialogue.

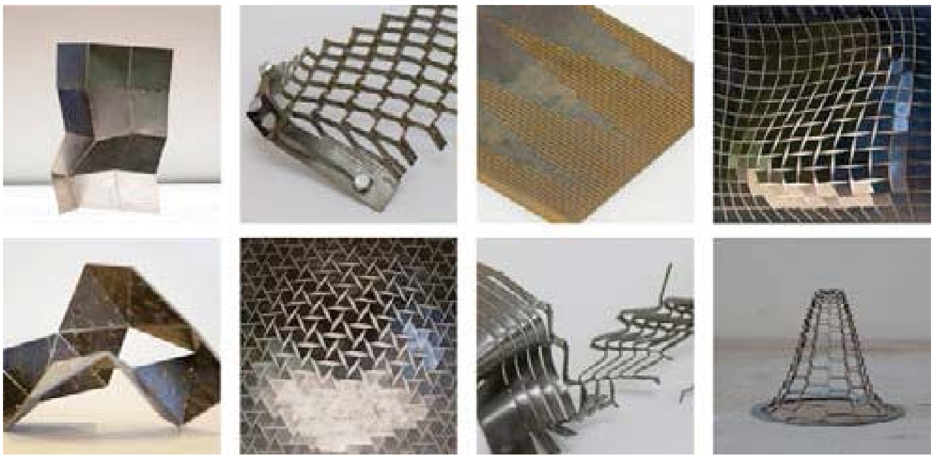

Figure 3.
A selection of experiments in sheet steel

Mesh focus

Through the explorations in sheet steel a focusing on stretched metal was mesh developed. The particular fascination by this technic should be found in two reasons. First the impressive structural potential created through the cutting and transformation of thin steel into stretched mesh. After the water jet followed instructions originating from digital drawing a force of up to 5000N is applied to the material. Local transformations in the mesh create plastic deformations (Fig. 4). These deformations are extremely strong and create stiffness to the areas where they are applied. The process from geometrical design, through production to straightforward material properties bridges the span between virtual and actuality.

ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 2 (2) / February 2015

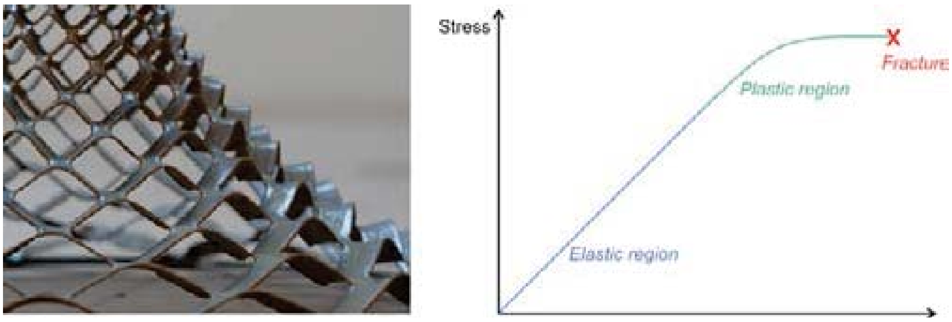

Figure 4.
The transformation of cut steel into mesh results in local plastic deformation. ("Deformation (engineering)," 2014)

Secondly the stretching involves and number of contributions to the dialogue between control and uncertainty. The creation of the mesh itself involves a number of crucial points where control of the material is necessary to realise the intended. The meshes are naturally depending on the design and configuration of the drawing. The water jet follows the control from the drawing and prepares for forthcoming transformation. The transformation itself requires precise control of the deformation (Fig.5). Both force and direction need attention if not uncertainty is allowed to take over. Even with precise metering of force no stretch turned out exactly the same. Inherent differences in the thin sheet steel had an impact on the final result. And sometimes uncertainty took over despite of the intention of control (Fig. 3).

Figure 5.
Two iterations of equipment for stretching steel into mesh.

On the contrary to the industrialised production of metal mesh, this set up investigation combines creative freedom with the power of a water jet cutter. Geometry and tool paths can take many forms, experimental stretching can be tried out and the meshes can change size and character within the found material and tool limits.
Initial experiments started out with a mapping of mesh sizes and sheet metal tolerances. Stretching methods and techniques were explored and roughly brought under control

ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 2 (2) / February 2015

(Fig. 6). From here different strategies and geometries were tested out. Linear and point stretching are more or less controllable including asymmetrical and amorphous shapes. Crooked and multi-directional stretching however includes a fair amount of uncertainty.

Figure 6.
Early mesh construction. Steel is almost under full control.

Levels of control

The quantity of steel experiments ensured an overall, however scattered, knowledge of different geometrical and transformable approaches to sheet steel. They established different ways of transferring drawn intention into material. With a workflow established and a well-developed mesh investigation more conceptual implementation of the knowledge started.
The steel mesh creates an exiting contrast to the floppy 0,5 mm steel from where it grows out. The structural capabilities of the meshed areas emphasises the level of control and precision that is encased in its production. Mesh and unprocessed steel outlines the levels of control that can be applied to the material through the explored processes. In between these extremes the folding, bending and other deformations on basis of drawn geometry is found. With these varying levels of control combined drawing sets can be created. Not solely on the basis of form or intended material behaviour, but as a strategy of embedding different levels of control into a piece of material and use this distribution as a devising factor (Fig. 7).

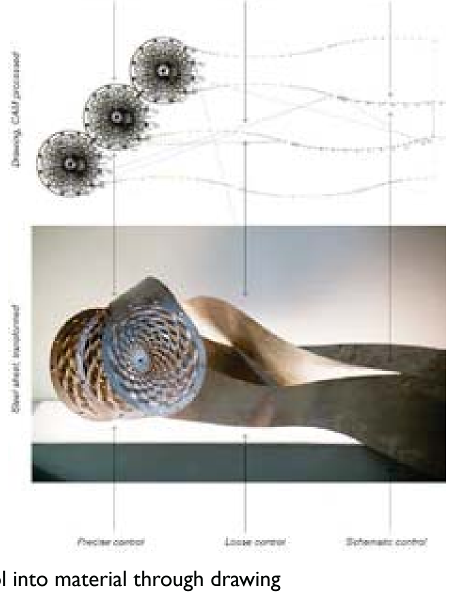

Figure 7.
Distribution of control into material through drawing

ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 2 (2) / February 2015

Towards architectural components

Taking the world of architecture into account the developed approach to steel sheets is applied to a set of structure types. The created artefacts are related to human scale, creating an intention and suggestion of a 1:1 use of the method. Other than being human size this series of experiments tries to incorporate certain architectural and structural occurrences. For instance; the beam, a shift from vertical to horizontal or varying structure density (Fig. 8). Since the method and technic not conceptually allows complete preceding designs the above description should be seen as intention that impacts the decision making wherever the architect directly appears in the process.
The produced artefacts are considered experiments along with their predecessors. However their genesis is also an experiment in itself. The process is a collage of contrasts and the results incorporate a new level of reality into the project.

Figure 8.
Selection of structures.

Back to virtuality

So far the created artefacts disciplined origins from the dialogue between the computer's digital domain and the specific material properties and capacities. The dialogue however has a clear direction moving from the digital starting point towards realisation and our perceived world. I may zigzag and shuttle back and forth on the way but the increasing materialisation and actualisation through the process is predominant.
The method with which the artefacts are being developed is characterised by a continued consent of the unplanned and autonomous. Therefore no exact description, drawing or simulation of the artefacts exists. The final results only exist as themselves, a physical output compromised of created and utilised information from drawing, fabrication and

ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 2 (2) / February 2015

material. The artefact hold highly controlled portions, which precisely correspond with intention, in some areas. Other places they consist of curves or folds that is either a dialogue between drawing and material or composed only by the material itself. Steel sheets curves the way they like to curve without any predefined external instruction set.
Within the transformation processes and formal output a lot of qualitative information is embedded. The natural curves might contain useful courses and the relationships within and between artefacts might hold interesting spatial information. In both cases the workflow preclude the possibility to extract this information from the data basis from where it origins – the drawing, codes…ect. To access and operationalise this information for further development the artefacts need to feed back information into a virtual domain, where plasticity exist.
Digital photography allows a subjective way of collecting information through the digital picture plane. 3D laser scanning takes the digitalisation to another level and combines millions of measured point with photographs to create a digital point based world on the basis of reality.
3D laser scanning makes it possible to directly jump from one extreme to another. Existing reality with indefinite amount of indefinable information can be digitised into points. Points have no area, volume or any other property than its relative position in a digital space. The point cloud is the extreme of sole digital existence, yet its relation to reality is easily perceived. Like reality the digital point cloud contains almost endless information that, in it self, is practically non-operative. Selection, processing and decision making is required to obtain usefulness. A virtualisation, a translation or processing, of the point cloud is needed for it to be more than just an endless amount of documentation.
The steel artefacts were intuitively arranged in an already existing space and digitised with a 3D laser scanner. An immediate outcome is the possibility to discuss and analyse the real world through the scan using existing architectural constructions and articulations. A representational, architectural section (Fig. 9) can be created and a parallel to the architectural drawing can be established. Within this experiment that option is important since the materialisation was created without any traditional drawing material. This now exists, chronological backwards. The processed steel now causes spatial, architectural representation. Architectural representation did not cause the processing of steel.

Figure 7.
3D laser scans create a digital section through reality

ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 2 (2) / February 2015

Because of its comprehensive nature, the point cloud do not function very well as direct operational information. The enormous amount of points does not instantly transform into useful geometry. But relevant information can be extracted accordingly to an intention. Again this is a matter of control. Full control of the digitised actual world might not be fertile at all. But specific, selected control in places of specific importance might be easily operational. A strategy for an operationalisation of the point cloud can be to single out points of special potential for further processing. This can be for the creation of splines or NURBS surfaces or other virtual existences. These transformations take the digitisation of the actual into being a process of defining variables instead of a passive documentation. This creates a linkage going from real actuality to digital virtuality.

With the use of modern metrology equipment the digitisation and virtualisation can however be combined to an interconnected action. Digital metrology arms can combine exact point definition and point cloud scanning (Figure 10). This makes the process of establishing the virtual an action that takes places in a tangible shuttling between the physical world and the digital. The virtualisation itself becomes a space of possibilities and choices.

Figure 10.
Combined scanning and metrology equipment. Digitisation and virtualisation as an interconnected process.

In this experiment, points along the curved steel where digitised and used as information for the creation of virtual splines in digital space. This way the material behaviour caused the creation of digital curvature (Figure 11).
With annexation of the curved steel into virtuality this project is put on pause. However the splines have the potential of initiating the next set of experiments and discussions. Easily they can become information for new drawing and production – and they probably will.

ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 2 (2) / February 2015

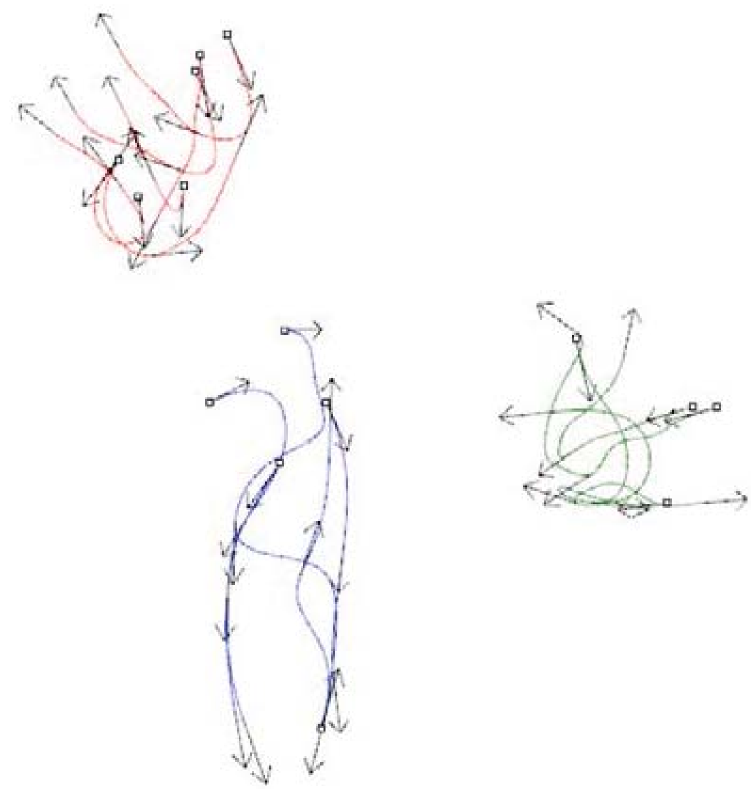

Figure 11.
Splines made from digitised points. Reality feeds back information to the virtual. Splines correspond with structural arrangement from figure 9.

Recapitulation and future research

The starting point of this paper – and the project underlying – is a method to the use of digital fabrication in an exploring architectural process. The goal of the approach is not to use digital fabrication as a tool set to realise digital, architectural ideas, but as instruments to connect the reality of materials and to an exploring process. The project sees the virtual domain as the approach to exchange information back and forth between the materials and the architect's intention.
As it, hopefully, becomes clear through in the exposition of the experiments, the relationship between control and uncertainty becomes important to the way the experiments and the project takes shape. This dialogue is related directly to the discussed relation between virtual and actual. The paper aims to focus on the opportunity of linking materiality to the digital drawing in a coherent way. It is the conception that material properties and capacities hold potential with which projects and experiments can develop. Consequently the aim is not to trump the material with superior control, but create a context where all can contribute. For this to happen, this paper suggests the method of distributed control and the encouragement of uncertainty. Without any control material would stay passive. It would not be affected or have the capacity to affect. As seen in the experiments, specific

ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 2 (2) / February 2015

control through the digital domain into the materials can trigger possibilities and allow for uncertainty to offers itself through the material's behaviour.
As explained, the experiments examined in this paper only represent a component in a larger project. The project also involves wood and concrete. The approach to these materials is similar to the steel in the way that it establishes dialogues between digital design intention and control factors and the materials. Wood and concrete offer very different material qualities than steel and hold completely different sets of capacities.
However the future step for this research project is to establish exchanging information between the materials and their different realities. This also means more complex, intermingled virtual situations where specific or universal control for different or all materials can be handled. The creation of digital splines from curves created in reality is an obvious example of a starting point for a multi material strategy. One material can create actual information that is virtualised, gets transformed, processed and becomes fabrication information for another material that again can meet the original material in reality. Together they now can create new information that becomes nutrition for further dialogue and development.

A far-reaching and more ambitious end of the subject of this paper is to fertilise and nourish architectural practices and design approaches where the digital domain and the reality of the material world are in mutual conversation. The development in digital fabrication machinery and supporting software is enabling the output of digital design tools to much more than picturing and passive actualisation of ideas. Design and realisation does not need to be split up affairs or a one-way process. A design practice of inclusive approaches, encompassing the full extends of both digital and material possibilities seem to have potential for architectural development.
Hopefully the intention and overall approach of the project comes through in this paper. It is the belief that both the interest and method presented here will be refined in the further investigation to come.

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ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 2 (2) / February 2015

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