Future Field

Design study on a building envelope with an experience of motion

by

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ABSTRACT

This thesis consists of a graduation project for the MSc Building Technologies at faculty of Architecture, the Delft University of Technology (TUDelft). The thesis is part of a double graduation program, called Strategic Architectural Design Development (SADD), by the chair of Materialisation, and combines this thesis with MSc Architecture.

The design study is split in two. The first phase of the design study focuses on the achievement of an ambition. The ambition recalls a metaphor of the motional effect in a field of wheat due to wind. It is a successful study towards a concept for the roof of the SBC which comply with architectural and urban requirements. The result is a concept called Future Field. It is an architectural integrated kinetic building envelope explicitly suitable for the SBC. Future Field exists of a field flexible strands that collect daylight and transmits light inwards through use of optic fibres. The human experience is highly influence light and therefore the light acts as a medium to generate an experience of motion. In the first conceptual design phase the aspect of electricity was introduced. But study proved the technology not feasible and outside realm of building technologic research.

The concept of Future Field is then further developed by obtaining the requirements of maximizing the experience of motion. By quantifying the illumination requirements and manipulating of the lighting effect, maximizing is reached. The internal experience of motion is attained by an additional illuminance fluctuation factor. This factor is perceived as the difference in brightness which is recognisable by the human eye. The standard requirements can be easily fulfilled by Future Field. But the minimal illumination of internal daylight cannot be fulfilled in relation to the illuminance fluctuation factor. Therefore the experience of motion of internal daylight cannot be maximised to the required values.
PREFACE

This thesis is the result of design study by Gijs Leffers as part of the graduation project for the MSc-degree at faculty of Architecture, the Delft University of Technology (TUDelft). The product of a building technological design research on a building envelope, conducted in MSc4. It is part of a double graduation program, called Strategic Architectural Design Development (SADD), by the chair of Materialisation.

Aim of the graduation program is to create as much interaction between Architecture and Building Technology. One program, two projects and a simultaneous design process of the different disciplines will encourage this interaction. Yet, this thesis is the result of one semester, 20 weeks, and is halfway down the graduation program. The outcome of this thesis will be applied final design, mostly the architectural part of the graduation program. And the final design of this building technological study will not be present in this thesis because the entire project is not finished. Although the design is not final, this study can be seen as the fundamental design development of SADD.

My educational career is the effect for my love of buildings. They are an object of design which has a tremendous influence on people. It is your home, a school or an office. It is a facilitation of cultural, economical and personal necessities. It can be a prestigious representation of a sociality or just a simple house to protect you from the outdoor environment. Function, meaning and technology are combined in architecture. Because of this mixture and my love for buildings an architectural degree is my personal goal. And with my technical background I find the combination of technology and design intriguing. And the simulations design development of SADD is therefore the reason I choose this graduation lab.

Throughout the design development of the SADD program I had many people whom assisted me realizing my ambition and striating my goals for this project. Their knowledge and expertise were crucial for a successful design. That is why I want to thank Frank Schnater for obtaining a certain level of progress throughout the semester. And Patrick Teuffel and Florian Heinzelmann for their criticism, it especially helped me to clarifying the main objective. Maarten Korpershoek and Jan van der Voort for the on-going architectural development. The expertise of Huib Plomp on the field of wind behaviour and implications for the build environment where also helpful. Furthermore I like to thank my colleges at Ingenieursbureau HOC BV. for their technical knowledge and sympathy. Next to the help of professionals I want acknowledge the support of fellow students. Michel Buijsen and Edward Sillem were actually most involved with the design purely out of curiosity. Last but far from least, I would like to thank my family and friends their love and support.

Sunday, 09 January 2011

L.G. Leffers
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METHODOLOGY

The thesis at hand is part of a larger and on-going combined graduation project. The field of research for building technology is determined by the architectural development and the result will be applied in the final design of the architecture. Both design researches, architecture and building technology, are interlaced. Yet, this thesis can be criticized separately. Explaining the setup of the thesis requires an understanding about design and research. Prof. dr. ir. T. M. de Jong for TUDelft makes the following theory about design related study and differences between research and design.

-A design does not follow unequivocally and reproductably from a programme like a scientific prediction repeatable from its basic assumption. In making a design, the preliminary investigation and its conclusion, the programme of requirements, direct the solution only partly. Even within the boundaries of strict programme, unexpected and unpredictable alternatives are possible in design. Most design decision about form, subsequent structure (set of necessary connections and separations to keep the form) and even subsequent function (freedom of unexpected use) must be made without empirical evidence. This is the most explicit in building design. The choice of final alternative is determined by the total context of the object to be designed. [...] The number of imaginable alternatives for buildings, mostly with a long term multi-functional programme of (conflicting) demands, is inconceivably large, subject to a combinatoric explosion of possible forms. [...]¹

In spite of kinship between research and design differences apply; the primary product of research is general knowledge in form of probability. In a more narrow sense it is also the description of existing reality or truth belonging to it. This knowledge may, or may not be applied in (design) practise. The primary product of designing is the representation of a possibility; also if it is not a likely one. A design demonstrates what is possible and thus may become reality. Knowledge of what is probable is always incorporated in a design, often implicitly; e.g. that a brick can endure a well-defined pressure.²

This thesis consist of a design development, a design related study. Although a design development can be hardly described as predictable step-by-step process, the thesis will be reported as such. In order to obtain a certain level of understanding of design decisions, the report will handle all aspects of the design in a certain step-by-step order.

The study is a quest for making a general idea, or concept, technically, spatially and expressively visible and viable. By making the design viable, a set of requirements or absolute conditions and hypothesis' need to be established. They can be drawn from scientific knowledge, empirical and experimental research on specific design steps. Certain design steps can be tested by those requirements or hypothesis'. Hereby research provide arguments for certain decisions. Research as an instrument for design rather than a product of scientific knowledge.

The study can be split up in two general phases namely; conceptual research phase with the specification design research and the technical design phase with the viable and product development.

¹ (Jong 2005, p. 19)
² (Jong 2005, p. 25)
The thesis starts by providing an educational framework to clarify the program of SADD and the following study. A general description of the urban and architectural conditions will follow the educational framework. This description is the contextual background of the building envelope and will function as the first set of requirements.

Then thesis is split in two main parts; the conceptual research phase and the main and more specific research phase. The separation in phases is made because an ambition, a general idea of a building envelope, is the fundamental core of the design. First, the idea itself is investigated and analyses on specific aspects. These aspects need specific requirements in order to make the fundamental idea viable. The set of requirements function as boundaries for a specified research. This specific research is makes up the second part of the entire study. Experiments were conducted during both phases to test the design and validate the potential. These experiments are placed in the appendices.
INTRODUCTION

Educational framework
This thesis is part of the graduation lab of SADD, a combined Architectural study with a study of Building Technologies. Aim of the graduation lab is to create as much interaction between Architecture and Building Technology. One program, two projects and a simultaneous design process of the different disciplines will encourage this interaction. The following thesis is the result of one semester, 20 weeks, and is halfway down the graduation program. The outcome of this thesis will be applied final design, the architectural part of the graduation program.

The combined graduation concerns a single building, namely Science Business Centre (SBC) at the Science/Business Park named Technopolis, Delft. The building houses different functions such as auditoria, a museum and offices. It is located on a newly designed master plan of the campus area, the Technical University of Delft. Generally the master plan and building design are presented as the architectural part of the graduation lab. The Building Technology part concerns a project named Future Field. Future Field is an architectural integrated kinetic building envelope. The project contains a design study on a translucent building envelope in motion, explicitly suitable for the architectural part of the graduation program.

While the Science business park is an actual urban development, all designs are fictive. For sake of educational purposes all designs are made by the student, only the urban development and the program of requirements is more or less real. Both designs of the master plan and building design will serve as a basis for this thesis. The design study of this thesis will be explicitly suitable for the architectural design of the SBC within the newly designed master plan of the Technopolis area. As stated before; the outcome of this design study will attain certain design requirements for the SBC.

Future Field concept
Future Field is a design concept which answers to the problem statement. It is an architectural integrated kinetic building envelope explicitly suitable for the SBC. Future Field will be applied on the architectural design of the SBC. It covers the slope roof of the exterior and shapes the inside space according to the results of this thesis.

Figure 1 Conceptual image of Future Field
Problem statement

As mentioned in the methodology the problem statement is divided into two pieces. In order to establish a wide conceptual design study this generally focuses on realising a method coherent to the ambition. Therefore the problem statement is presented in the following way;

Problem statement 1.0

*There is no building envelope that generates an experience of motion, explicitly suitable for the SBC.*

When the main research problem is answered by a fundamental concept, the statement is specified. Based on this fundamental concept the design development will necessitate a more precise definition of sake of further study. Thus a more specific problem statement can be formulated as follows:

Problem statement 2.0

*There is no roof design that generate and maximizes an experience of motion through daylight and fibre optic, explicitly suitable for the SBC.*
CONTEXT

Urban development

The Technopolis innovation park is a new development in the city of Delft and in immediate vicinity of the Delft University of Technology. Within 20 years this shared business campus should be fully occupied with knowledge-intensive companies that expand the boundaries of new applications. The science business park focuses on research and development (R&D) centres, and European branches of R&D-intensive companies. Knowledge, expertise and research facilities are all at hand.

There is a national policy towards the development of a knowledge driven economy. Education and innovation are crucial for intensifying knowledge and expertise. There are different areas in the Netherlands pointed out that can count on special support of the national government. One of these key areas is the TUDelft area with a special attention towards technology. The importance of this development is seen is a special innovation platform which is setup to help organize this ambition. Under supervision of the ex-minister-president J.P. Balkenende Holland and especially the key areas need to attract highly innovative and knowledge intensive companies.

The Technopolis innovation park revolves around innovative technology. Businesses, institutions and university at the Technopolis are neighbours and share a common interest in technology. Cooperation between the three parties can be improved to extent the concentration of knowledge. Collaboration between people like students, researchers and corporate employees’ leads new inventions in the field of technology. Working together and sharing knowledge is the key to the new development of Technopolis.

The site for the Technopolis area is next to the existing part of the university campus. It is located on the edge of the Midden-Delfland. This will be developed as an experimental polder landscape and a large thematic leisure area. The context of technology and the location in a polder are complementary to the vision of Technopolis Innovation Park. Polders are a sophisticated form of landscape technology. In fact Holland and especially TUDelft together with Deltares are among the world leaders of expertise in water management and landscape technologies. Technopolis’ centre, the heart of the innovation park is thereby inspired by ‘polderlandschap’. A large open plane of nature, water and greenery, with only a few buildings enclosed in a frame of a dense urban district which consists of 30 meter high office blocks. Here the polder landscape plays an active role in the development of the Technopolis Innovation Park. Next to a central area for nature and leisure, it emphasizes landscape technology and the area of expertise of the innovation park as a whole.

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3 (Güller Güller architecture urbanism, 2009)
Architecture
The SBC (SBC) is literally and functionally in heart of the Technopolis innovation park. It embodies the aspiration of Technopolis as a platform of technologic innovations and sharing of knowledge. The building houses different functions such as conference arias and dining facilities for commercial and educational purposes. The building serves as an extension of facilities of the Delft University of Technology and offers common ground in the Technopolis Innovation Park making the university more accessible. The SBC will also house a museum which permanently exhibits the technical accomplishments of the university and the temporary exhibitions of the innovations of the Technopolis Innovation Park. The SBC is a place to be inspired by the marvels of modern technical achievements and dream about future possibilities.

The design of the SBC exists visually of two building volumes, split by a public route for pedestrians and cyclists. The main entrée of the SBC is located at this path which connects the polder landscape to the rest of the innovation park. The two building volumes have slowly rising rooftops for the ground up. The roof is partially accessible for public. The roof is the main feature of the building and should express the concept of the SBC and the Innovation Park as a whole. The building volumes are orientated in the main wind directions to reduce extreme wind on the roof. The roof sloops are put towards the polder landscape to reduce the impact within the polder. The idea is to establish a relation between the low-tech polder landscape and an expressive high-tech roof landscape that embodies the SBC. Inspiration is the key to a successful design of the SBC.

Architectural requirements
The roof emphasizes the concept of the technological landscape complimentary to the function of the museum, conference etc. It will be the embodiment of the TUDelft and Technopolis Innovation Park. Inspiration is the key to a successful design of the SBC. Within this context the research and design proposal for Building Technology is formulated.

Figure 3 Application of Future Field in red


AMBITION

Main objective
The ambition is to create a building envelope that embodies an experience of motion. Uncontrollable motion, not violent nor rough but unpredictable and erratic like the waving wheat fields or a gentle struggle of leaves in the wind.

It is not the actual motion itself that drives this ambition but what motion expresses. The experience of moment and time. The building will lose its static appearance and become dynamic. By choosing wind energy to trigger the dynamic effect the building plays an active role in its ever-changing environment due to the weather conditions.

The dynamic effect will trigger the experience of motion by people and therefore the experience needs to be emphasised. The experience of motion must have a positive effect on people and embody the technical context of the SBC and Technopolis Innovation Park.

Visualization
In order to get better understanding of the idea of motion, the following sequence of images visualises the ambition.

Figure 4: Field in motion

Requirements of ambition
The roof will need to emphasizes the idea of the technological landscape complimentary to the function of the museum, conference etc. It requires the embodiment of the TUDelft and Technopolis Innovation Park by using a field in motion as the concept.

Problem statement 1.0
Basically the roof of the SBC requires a dynamic building envelope. An envelope with the same effect as a field of grass moving in the wind. The roof requires the technical appearance which articulate the specific building design. Thus a general problem statement can be formulated as follows:

There is no building envelope that generates an experience of motion, explicitly suitable for the SBC.

Research question 1.0
Subsequently, a main research question arises to articulate the problem concerning the ambition. Thus the main research, within the context of the ambition, runs as follows;

How can a building envelope generate an experience of motion, explicitly suitable for the SBC?
CONCEPTUAL RESEARCH

Experience
Experience refers to the nature of the events someone or something has undergone. Experience is what is happening to us all the time - as we long we exist. Experience refers to the subjective nature of one's current existence. Humans have a myriad of expressions, behaviours, emotions, etc. that characterize and convey our moment-to-moment experiences. [...] Past and present experience emerge from a critical connection and philosophical issue: To what extent do one's past experiences influence one's current and future experience?

The idea that past experiences influence future experiences was termed continuity by John Dewey. All experiences, argued Dewey, impact on one’s future, for better or worse. Basically, cumulative experience either shuts one down or opens up one's access to possible future experiences.

- Aldous Huxley

When referring to an 'experience of motion' one needs to question motion as well as the experience. This introduction on the meaning of experience stretches the basic intent of the building’s architecture and concept of motion. Without going deeper in the philosophical meaning, experiences can "open up one’s access to possible future experiences". The experience can inspire people to think about future developments. Thereby stimulating the technical innovations at the science and business park. Thus, specific experience is subject of the research question. The undergoing of people's experience is the subject to one's senses. Without elaborating on the basic five senses or even the biological and psychical elements of multiple organ sensory, the focus is on sight. The human experience, conscious or not, exists for a large majority of visual sensory e.g. light. Sight requires light which is a fundamental tool of architecture. So, without further or do, the assumption is made to express the motional effect with light. The experience is especially achieved by using light as a medium. To maximize the experience, light will play a subsequent role in the atmosphere of the SBC.

Conceptual requirements for experience
To achieve an experience of motion light will be used as a medium.
Field of conceptual research

Experience of motion has to do with kinetic energy and the visual impact of the façade. The kinetic energy is the motion itself, and visual impact is a combination of motion and light. As stated before light as a medium can have a dramatic effect on people. The experience of motion can be enhanced because people are visually very sensitive. And since the aim is an embodiment of technological innovation within a dynamic building envelope, the idea arises of energy production. The required kinetic energy can be transformed in electric energy and thus produce electricity. A kinetic building envelope that produces electricity can be seen as an technical innovation thus comply with the design requirements.

![Diagram of Experience of motion]

**Figure 5: Features of Future Field**

To create an architectural integrated kinetic building envelope can produce energy and provide sufficient lighting, explicitly suitable for the SBC. An idea that embodies the technical innovation necessary for the assignment. There are now three main features derived from the prior assessment of the experience of motion; motion itself, electricity and lighting. The distinction between those characteristics requires a short introduction before further study.

**Motion**

The vision of a field of grass moved by wind is a very abstract description of the desired goal. By a changing a conventional exterior in a dynamic one, the roof will lose its static appearance. The intension is not to imitate a natural environment but to achieve the same effect of a field of grass in motion. By analysing different motions by wind, ways of triggering the same effect will arise. A preliminary field experiment (Appendix 2, experimental series 1) is conducted to confirm the initial thought of ‘the field’. The ambition for motion is best described as a surface area with discreet ‘waves’ caused by gusts of wind namely; a field. Furthermore methods for creating an internal effect of motion acquire attention. There are certain consequences to dynamics. If there are others ways of expressing the motion effect they have to be taken into account.

**Conceptual requirements for motion**

Mimic the effect of a field in motion on the exterior of the roof.
And a method for creating motional effect interiorly.
Electricity

Energy harvesting is the process by which energy is derived from external sources, in this case wind energy, captured and either immediately used or stored. The alternative, large-scale ambient energy source are widely available but technologies do not exist to capture it with great efficiency. Energy harvesters currently do not produce sufficient energy to perform heavy mechanical work, but instead provide very small amount of power for powering low-energy electronics. There is no illusion of changing these facts and revolutionizing technology. Instead the challenge is only to find a potential to provide immediate electric energy in the SBC. The produced electricity can actively provide the artificial lighting. The locally generated power can be experienced by a fluctuating in artificial lighting in its immediate vicinity. Motion will generate electricity and power lighting which is consistent with the ambition of experiencing motion.

Conceptual requirements for electricity

Sufficient generation of electric energy for powering artificial lighting.

Lighting

When energy is produced the electric lighting will shine. Because of the wind, energy production will fluctuate and lighting will go on and off. Covering the entire ceiling with lighting that is locally connected to the separate Future Field elements will reflect the wind. Lighting will lit up when energy is produced. The changing wind patterns result is waves of artificial light moving over the ceiling. It reflects the motional behaviour of Future Field and the wind. It consists of additional lighting that gives the impression of motion in a high-tech ambiance. Thus the ceiling of the roof of the building becomes an essential part of the realization of Future Field. By covering the ceiling with a finish that is coherent to the design as a whole experience of Future Field will be impressive from outside and inside the building. The finishing must echo an ambiance of technology, special lighting effects from the ceiling can achieve this.

The exterior of Future Field can also be lit for the same reason as the interior. But only during dark when the exterior motion cannot be seen. The fluctuation in light reflect wind patterns and delivers a high-tech landscape during dark. This idea would answer to the concept of the SBC and Technopolis Innovation Park.

Conceptual requirements for lighting

The special effects in artificial lighting that offer an ambiance of high-technology combined with motional reflections of the alternative source; wind energy.
Precedential research

The ambition of a kinetic building envelope is highly abstract and does not provide sufficient framework to point out a direction. The elaboration on different aspects of the experience of motion clarifies an intension but is also ambiguously and not precise. In order to get a better understanding, a study of precedents is presented to gain more progress and direction in the design development of a kinetic building envelope. Several artworks and advanced studies give an idea of this graduation project.

The first art- and architectural work gives a visual idea of the proposal at hand. "Fibre Tower" is the work of Makoto Sei Watanabe. Glass fibre threads move slowly in the wind like fields of wheat. In this vision kinetic energy is captured by what looks like a technologic landscape of the future where you really harvest energy. The subtle movement of this high-tech material would provoke the architecture of the future. The architectural design is enormous and seems ambitious.

The second artwork is of Daan Roosegaarde and his studio being "Dune 4.2". A permanent interactive landscape which is located besides the river Maas in Rotterdam. This public artwork of 60 meters long utilizes less than 60 Watts while intuitively interacting with the behaviour of its visitors. It gives an idea of the technologic landscape which can be a result of the proposed innovative future envelope. The interactive aspects of this project are appealing but form no goals whatsoever.

The second, more advanced study, is called "Super Cilia Skin", a multi-modal interactive membrane. "Super Cilia Skin" is conceived as a computationally enhanced membrane coupling tactile kinaesthetic input with tactile and visual output. Again, the interactive aspects of this project are interesting and even mind blowing, but not one of the goals for this project. The relation to the proposal is the technology which is used. Electronic regulated magnetic fields are controlling the mechanical movement of sensors. This principle can be turned around. Mechanical movement caused by wind can result in changing magnetic fields which generates electric energy.
“Solar Ivy” is a solar generated project. It is a unique system of free and independently movable ‘leafs’ with PV modules. The system claims to be very sustainable by either re-use or recycling of synthetic materials. Solar Ivy is a flexible gladding system which can be adapted to most buildings, even existing ones. Because of its modular design repairs or replacements can be easily dealt with. The sustainability of the product is remarkable but it's the motion of leafs that form an inspiration to this project. It exists as a gladding material providing movement and energy production similar to the idea of this project. The difference is sun power instead of wind power. Furthermore the “Future Field” is not a gladding but an building envelope.

The last project is the UK pavilion in the Shanghai Expo 2010, by Heatherwick Studio. One of the aims of this pavilion is to be a direct manifestation of the content it exhibits. These aims are captured in two interlinked and experiential elements based around the subject of nature and cities namely “The Seed Cathedral”. It is constructed from long transparent optical strands with an embedded seed which are 7.5-meter. The interior is illuminated only by the daylight through each optical hair. The architectural thoughts behind this pavilion are admirable, but very different than the idea of Future Field. However, its expression can have a large similarity. The movement of the long optical strands by the wind can be combined with the idea of converting energy.
Motion

Conceptual analysis of exterior motion

Figure 12 Analysis of desired motion of a surface

So, Future Field revolves around the concept of motion. It is concluded that the exteriorly effect of motion has to mimic a field of grass in the wind. (Appendix 2, Experimental Series1) The field needs to have a primarily 2D surface area, be it on a large scale; the roof of the SBC. The creation of modest ‘waves’ by gusts of wind will result in mimicking the motional effect. A field can be abstracted into points instead of a surface. The creation of motion within points due to wind is more feasible than one large surface. When the concentration of points is high enough, the effect of a field will remain. The analyses are extensive while the result is a simple abstraction of a field.

Figure 13 Analysis of desired motion of a field

Scale

Another aspect of the field is its scale. The term ‘field’ will subsequently have an idea or image in people’s head. It can be considered as an area, primarily with an overview of it size. The field in perspective to the SBC can be seen as a landscape. This landscape will mostly be viewed from a distance with a few exceptions. These exceptions are important for the experience of motion, thus the field. When the field requires overview close by to mimic the motional effect, it immediately requires a certain level of scale. It cannot be higher than eye level; it will obscure the view thus motional effect. Besides, the field can be experienced like a forest or some sort. This is absolutely not the goal of the exterior. A small scale, in relation to people will also have an undesired consequence. A smaller scale will decrease the motional effect of the field. The ‘waves’ will be tiny and unrecognisable from a distance, killing the experience and missing the architectural requirements.

The vision of a field of grass moved by wind is a very abstract description of the desired goal. To visualize the desired motion and possibly qualify it empirically can form objectives in further design study. A certain motional behaviour can be captured in a photograph or film. Analysing these images deliver a clearer picture and a validation of design decisions.

Furthermore, wind analysis is required to gain insight about environment at which Future Field is exposed. The motional behaviour of Future Field is initially the cause of metrological conditions of the wind. With basic knowledge of the urban plan, the SBC and Future Field’s appearance these conditions can result in further design requirements.
Conceptual analysis of interior effect

While the ambition is revealing a motional behaviour of the exterior namely in gentle ‘waves’ or field effects, the interior only speaks about light fluctuations. In order to clarify the intentional effect of the interior of the SBC, experiments were conducted by using a simple cardboard box. (Appendix B, experimental series 2) The experiments where inspired by the precedential research on building technologic methods of movement and light fluctuations. Light fluctuations need to activate an experience of motion. Light fluctuation coherent to the ‘waves’ of the motional effect of the field are a successful method for the interior experience of motion. Transmitting light trough fibre optics provides an intensive experience and proves great potential. Further study on the matter is required. The experiments also reveal potential alternatives for artificial light fluctuation by shading methods or light bundles. Light bundles are considered to be more intense and therefore more effective for the concept of motion.

![Figure 14 Experimental effects of interior lighting](image)

Specific requirements for motion

Exteriorly

- Primary the field needs to cover a 2D surface area that requires an overview for people.
- The field will exists of multiple endpoints of strands that make up the surface area.
- The initial actor of motional behaviour requires further analysis on the level of the SBC.

Interiorly

- Light requires fluctuation coherent to the motional effect of the field. When the wind blows the light actives.
- The fluctuation of light need to be recognisable by the human eye.
Electricity

Conceptual analysis of energy production

The general requirements of motion reveal the choice of strands. The field will consist of multiple strands that individually move. Together, as an entire field, they have the correct motional effect. Further study on the aspect of producing electricity will be based on these general requirements of motion.

Energy conversion

The kinetic energy of the wind will be captured by a mechanical movement of “the field”. The field will generate a certain back and forth motion that needs to be converted. This movement is very different from the conventional method of wind turbines that use rotational movements. The back and forth movement will therefore be converted by the piezoelectric effect. The piezoelectric effect will convert mechanical strain into a small electric current. Almost all piezoelectric generated currents produce enough electricity to power small devices as self-winding (quarts-) watches or a self-generating remote control for TV. But the large surface area of future field will be answerable to the ambient lighting demands of the SBC.

There are four methods distinguished for transformation motion. The freely moving strands must activate a useful movement which can generate power. First method to transform kinetic energy is by using rotation. This method is mostly applied in self-winding watches. Second method is the connection to a rotational hinge that generate a linear movement. The linear movement creates pressure in a piston which can be converted in an electric current. The third option is placed at the base of the strand. A container with a flexible head can capture kinetic energy and active ever chasing pressures. These pressures can be converted into an electric current. All three methods have the disadvantage of converting the kinetic energy of one strand. There are simple to many strands within the field to convert energy. The four methods have the advantage of a multiple strand generation. Two or more strands can convert energy at ones. There are two layers at the base of a bundle of strands, one of which is flexible. The flexible layer is placed above the static base layer. The deformation cause by kinetic energy within the strands will generate pressure. The pressure can, just as the other methods, be converted into an electric current.
**Piezoelectric theory**

Harvesting energy from piezoelectric effect is a widely investigated phenomenon since the last 20 years or so. The technology is very promising but needs research for wide application. Examples of innovative projects are the "Sustainable dance floor" and the "Super Cilia Skin". The emerging technology of Piezoelectricity is perfectly suitable within the context of the SBC and the Technopolis Innovation Park.

![Piezoelectric diagram](image)

To generate a voltage by mechanical strain, piezoelectric materials have to be used. Quartz Crystal has the ability to transform the mechanical strain energy into electrical charge. It is silicon and oxygen based material arranged in a crystalline structure (SiO2). This material is found in abundance in nature on the bases of non-crystalline structure like sand. Basically, silicon exists of positively charged atoms and oxygen of negatively charged atoms. A change within the configuration of the atoms results in a small current. Deformation of the material causes compression and tension in the crystalline structure and changes this configuration.
The sustainable dance floor is piezoelectric systems that convert motion from the human body into electrical power. The varying pressure on the different floor tiles causes the mechanical strain needed to generate electricity. In the case of future field the motion by wind is back and forth, not up and done like the dance floor. This results in a difficulty for producing enough mechanical strain. However, the research project of Super Cilia Skin has a better suitable solution for generating mechanical strain by a back and forth motion.

Super Cilia Skin is a field of actuators that swing in response to a magnetic force. The actuator is a small stick with a magnet at the base. There is cotton placed at tip of the strand for tactile purposes only. The strands are anchored in the middle by a silicone membrane by two plastic nuts. The membrane reacts elastically to the magnetic force applied by the magnets below and thereby deforms. The deformation of the membrane steer the strand a coordinated angle. After the deformation by magnets the membrane will spring back to its original state.

The magnets below the membrane are activated by electricity; electromagnets. The field of (small) electromagnets are called the Actuated Workbench which can dynamically control the area of magnets by a computer. The amounts of electromagnets determine a fluid motion. A computer, thus the membrane can either be preprogramed or be actively guided by individuals making it an interactive surface.

In summary the Super Cilia Skin uses the piëzo-effect in the silicone membrane. It is magnetic polarization which causes mechanical strain, deformation. The electromagnets are charged by electricity but can be reversed. The movement of cotton sticks deform the silicone membrane causing magnetic fields which generate electricity by means of electromagnets.

**Specific requirements for electricity**

There is no specific requirement setup for the electricity aspect of Future Field. The application of a similar technology like Super Cilia Skin will make the aspect of electricity possible. Yet, research studies on the specific conversion methods like Super Cilia Skin are slim and highly conceptual. But because these technologies are sophisticated and in the early phase of its development further research is required. This research exceeds building technologic studies and requires extensive knowledge in the field of electro mechanics. The existing researches provide ground for the hypothesis that piezoelectric technology can produce electricity. Yet, Future Field is merely in its early phases and electricity is just one of the aspects. The choice is made to dismiss the thought of producing electricity. It is simple not feasible to meet the conceptual requirements of electricity or even demand new ones. So, there can be no sufficient generation of electric energy to power artificial lighting, coherent to the concept of Future Field.
Lighting

Conceptual analysis of lighting effects

The requirements of motion for the interior effect remain, while the aspect of electricity is terminated. There are still light fluctuations demanded to mimic the motional effect interiorly. Without generating artificial lighting itself, the circle of aspects is broken. Yet, the conceptual model and experiments provide evidence to an even better solution then lighting: daylight. (Appendix B, experimental series 2&3) Subsequently, the use of fibre optic combined with daylight seems a high potential for a succesful Future Field design. Daylight can be transmitted through fibre optics inside the SBC. And daylight would also require a fluctuation coherent to the ‘waves’ of the motional effect. When the wind blows the daylight will shine in differentiated brightness’s.

Sunlight

The experience of sunlight in a room is exclusively different from that of artificial light. The sunlight has a continuous colour spectrum that makes it healthy. It is also living and dynamic, following the conditions of the outdoor light. Yet it is calm in its character and does not suffer from the hardly noticeable, but brain disturbing flickering of electrical light. Flickering is considered to be a highly intensive on-and-off light, while the fluctuations of Future Field are merely nuances in ambient space. This concept brings out the positive properties of sunlight and combines it with an additional experience of motion. But even more consideration must be taken to how different areas can come to life when illuminated with the bright and dynamic sunlight.

Illuminating interiors with daylight gains many benefits ranging from increased alertness to even reduce global warming i.e. reduction of artificial lighting. The concept aims at establishing a connection to the outdoor environment. Having the sun as light source, Future Field does not transfer light when clouds block the sun. This dynamic aspect is one key element of natural light that can be missed. Unfortunately this is a fact that cannot be change. A solution is require in order to fluctuate daylight interiorly at times the sun is totally block by grey skies. The option of night lighting actually still remains. The use of daylight makes the building envelope translucent. At night the interior lighting will shine towards the outside. So, even at night the exterior effect of motion remains.
**Requirements of illuminance**

The SBC houses different functions, each with its own demands concern light. Future Field will facilitate most of the daylight requirements for the central area of the museum, and the central area of the conference building. These central areas will function mostly as a lobby, meeting point for guests, students and employees. Because of their open plan the lobbies also have additional functions. Functions like flexible workspaces, presentation areas and a gallery are examples but, they will have additional daylight at the facades. All rooms which are to be used for permanent occupation must be provided with adequate natural light. In addition, appropriate visual links with the outside world will be assured. These rooms are placed at the façade of the SBC and are primary not equipped with Future Field. Therefore the requirements for daylight will only be specified for the internal areas that will be equipped with Future Field.

The necessary lighting intensity or illuminance (E) is 2000lx for optimum sight, around 750lx for a workplace and a minimal of 300lx for the lobby areas.\(^4\) For specific requirements a model of the SBC is displayed containing the minimum quantities of illuminance. The plans only reveal the requirements of area equipped with Future Field. The quantities reveal only the total demand for minimal of illuminance. That contains daylight through Future Field, the facades and by use of artificial lighting.

<table>
<thead>
<tr>
<th>Illuminance (E)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 – 150 lx</td>
<td>orientation in rooms for short-stay periods</td>
</tr>
<tr>
<td>150 – 200 lx</td>
<td>work areas not in constant use</td>
</tr>
<tr>
<td>200 – 300 lx</td>
<td>visual tasks of little difficulty</td>
</tr>
<tr>
<td>300 – 500 lx</td>
<td>visual tasks of moderate difficulty</td>
</tr>
<tr>
<td>500 – 750 lx</td>
<td>visual task of higher difficulty, e.g. office work</td>
</tr>
</tbody>
</table>

\(^5\) (Neufert, 2000, pp. 147-149)

**Specific requirements for lighting**

- Light fluctuations must be perceived by the human eye.
- Transmitting fluctuations of daylight through fibre optics.
- Specific research on the use of fibre optic is required.
- Specific circumstances of daylight be analysed for valid use in design.
- Specific requirements interior illuminance must be fulfilled.

\(^4\) (Linden, 2000, p. 81)
SPECIFIC DESIGN STUDY

Field of specific design study
Experience of motion has to do with kinetic energy and the visual impact of the roof design. The kinetic energy is the motion itself, and visual impact is a combination of motion and light. Both aspects are crucial for a correct experience at the SBC. The aspect of electricity did actually have an indirect relation towards the experience. The production of electric energy would be considered innovative, an architectural requirement, but part of the main objective. After the conceptual design phase it can be concluded that the experience of motion can be successful without electricity. Consequently, electricity would merely be an additive.

Figure 22 Framework of Future Field adjustment
While the main objective remains, the framework of Future Field is adjusted to the outcome of the conceptual design studies. During the conceptual design phase several subjects of Future Field were passed in review. The different identities were judged according the requirements set out through the first phase. Consequently, the basic shape of Future Field came about and the concept was formed. Figure 23 illustrates the outcome of the conceptual design studies and from a starting point for the specific design study.

Figure 23 Concept state of Future Field
Specific objective
Throughout the conceptual design phase specific requirements were demanded. These demands make the design study on Future Field viable by ensuring a sustainable research. It is necessary to fulfil all of specific requirements. For sake of completeness and clarification, the specific requirements are arranged.

Specific requirements for motion
Exteriorly
- Primary the field needs to cover a 2D surface area that requires an overview for people.
- The field will exists of multiple endpoints of strands that make up the surface area.
- The initial actor of motional behaviour requires further analysis on the level of the SBC.

Interiorly
- Light requires fluctuation coherent to the motional effect of the field.
- The fluctuation of light need to be recognisable by the human eye.

Specific requirements for lighting
- Light fluctuations must be perceived by the human eye.
- Transmitting fluctuations of daylight through fibre optics.
- Specific research on the use of fibre optic is required.
- Specific circumstances of daylight be analysed for valid use in design.
- Specific requirements interior illuminance must be fulfilled.

It is of great importance that during the specific design phase the conceptual requirements always need consideration. With the exception of producing electric energy. Specific design study will ensure the architectural and urban demands. And the main objective stands but can be specified like the requirements of Future Field.

The ambition is to create a building envelope that embodies an experience of motion. The motional effect will be enhanced by using daylight and fibre optic technology. The aim is to maximize the experience of motion with the context of the SBC.

Problem statement 2.0
Now that the main research question is partly answered by an fundamental concept. Based on this fundamental concept the design will necessitate a more precise definition of sake of further study. Thus a more specific problem statement can be formulated as follows:

There is no roof design that generate and maximizes an experience of motion through daylight and fibre optic, explicitly suitable for the SBC.

Research question 2.0
Subsequently, the more specified research question is formulated;

How can the roof of the SBC generate and maximise an experience of motion by use of daylight and fibre optics?
Fibre Optics

Although the fibre optic industry is large, technology is primarily used in the communication industry. Large amounts of data is transferred into light signals and transmitted through fibre optic cables at exceptionally high speed. Fibre optic technology for illumination requires another approach but equals the function of a medium of transmitting light. The concept of fibre optic functional architectural lighting is very simple. The light source assembly is located away from the area to be illuminated. Most application in architecture uses artificial light as a source. Basically, a lamp is placed in a closed box connected to many optic cables. The cable will lead to a transmitting point at another location and shines from there. The Cathedral of Nantes is an example of this application.

Other technics use daylight to lighten internal areas which lack natural light. Instead of the closed light box they use light collectors at the top or sides of building, wherever the concentration of daylight is the highest. These sunlight collectors can be equipped with a sun following system, a tracking devise to collect as much light as possible.

All technics in fibre optics have a similar disadvantage; a generally weakest point is the bending capability of the fibres. The fibres are of very flexible but can only bend to a certain point where after it breaks. A broken fibre will have a diminishing light transmission. However, the bending radius of most fibres is large, anywhere from 30 to 150mm for 90° angle. Therefore this general weak point does not threaten the flexible abilities of Future Field.

The fibre optic material can either exist of glass or plastic. Generally, glass is more clear but also expensive and the plastic option is cheaper but transmits less light. Both the reduction and absorption of plastic fibres are higher than glass, typically 300/400 dB/km, compared to 130/150 dB/km for glass. The lower the number, the better the light transmission. The light diminishment of typical plastic quality is around 7% per metre and that of typical glass fibre is 3% per metre. This means that the general light loss occur more quickly with plastic fibre than glass.

Generally, the lighting systems all have three the same components; the light source, a fibre optic light guide and fittings for connection. In case of Future Field the light source is daylight. And the kinetic building component of Future Field will be equipped with a collector at the endpoint. The strands serve as the light guide which will be fitted of the building envelope.

The fibres itself can be divided into two different categories namely, end-emitting and side-emitting fibres. The categories speak for themselves; the first transmits light towards the end of the fibre while the latter is transmitting most of the light to all sides. These side-emitting light guides are useful for signage and decoration. Future Field will be equipped with and end-emitting fibres in order to focus bright light on the functions of the SBC rather than on its own. Future Field must be experienced as part of the building and not as an object on its own.

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6 (Kay, 1999)
7 (The Dow Chemical Company, 2011)
THEORY

Influence of daylight

Wherever people are involved in intellectual work or learning, it’s crucial to provide a supportive environment that keeps the brain relaxed, the mind alert and the body healthy. Research proves that natural light will enable this. During experiments students in the classrooms with most natural light progressed 20% faster on math tests and 26% faster on reading tests. Workforce studies show how productivity increases by typically 6-16%, absence decreases by around 5-25%. It stretches the importance of sufficient daylight in office and educational areas.

And although the economic context is left out of the design study, it is worthy to point out the consequence of human reaction on effective daylight conditions; 1 per cent productivity increase equals the total energy cost in office buildings.9

Not only are the offices areas in the SBC better off with daylight. Galleries and museums can show art, paintings and sculptures, in the natural light when harmful ultraviolet is filtered out of the light. It is possible if the material only transfers the visible light of total solar radiation. This way artwork, textiles and so forth will not degrade. The heat-intensive infrared radiation that requires energy-consuming cooling is can also be filtered away.

Pure sunlight is dynamic and has a full spectrum that triggers the ganglion cells, which controls levels of melatonin and cortisol, thereby synchronizing the body clock. This makes us alert daytime and sleep well night-time, enhancing our immune systems and general health. Sunlight gives improved visibility from improved light, better colour rendering, and the absence of flickering from electrical lighting.10

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8 (Edwards, 2002)
9 (Journal of Property Management, 2000)
10 (Edwards, 2002)
Lighting conditions

The perceived radiation of light by the human eyes is measured in terms of the luminous flux (\(\varphi\)). The luminous flux radiated in a defined direction is known as the light intensity (I). The basis for determining the luminous flux is a point source. A point source of light that shines in any direction resulting in a diminishing of illuminance in relation to distance. However, Future Field is point source but an illuminated surface with a vertical orientation. Therefore the decreasing illuminance of Future Field as a whole is negligible. This hypothesis is based on the small ratio between the illuminated surface area and the height of the light source. The method of distribution the light intensity is called the distribution curve. This characterises the radiation of the source. A spotlight for instance is narrow and Future Field can be characterised as wide surface spread distribution of light. Thus, Future Field can be best characterised as a diffuse ambient skylight.

The necessary lighting intensity or illuminance (E) is 2000lx for optimum sight, around 750lx for a workplace and a minimal of 300lx for the lobby areas. For specific quantities is referred to the conceptual design phase concerning the requirements for illuminance.\(^{11}\) It is important to point out that the requirements for illuminance are artificial light and daylight combined. And that Future Field subjected to the illuminance of internal areas, and lighting conditions surrounding objects, like art, is not attended to. Because the intension of Future Field is a perceivable ambient daylight fluctuation, the artificial lights provide a steady and sustainable level of illuminance. In other words; the motional effect is expressed in illuminance by daylight, while the additive artificial lighting retains a minimum amount of lighting for the internal areas. Augmenting natural daylight with artful light can be done by automatically switching the artificial light on when certain levels of sunlight are reached. A minimal of 2/3 of the total required illuminance is required by Future Field. The general assumption is that the remaining 1/3 of the illuminance is generated by natural light from the façade and artificial lighting.

The fluctuation in daylight will subsequently be a differentiation between ambient and directional lighting. When sunlight shines direct in the collector of Future Field it creates a local brightness in the interior. The indirect daylight provides an ambient illuminance. Everything in the space does not have to be at the same light level. The entire area need not to be lit throughout at the same brightness. Rather, the equivalent of modulation and syncopation in music should be employed in illumination. In most places, ambient light, sufficient to avoid bumping into the furniture, can be combined with directional highlighting on the experience of motion produce an interesting effect-contrasting high an lows.

\(^{11}\) Requirements of illuminance, p26
Lighting implication
Light exists as part of electromagnetic radiation. It makes up only a small band of wavelength relevant to the entire spectrum of electromagnetic radiation, namely 380 to 780nm in length. The wavelength of radiation determines the visible colour; violet for short waves to red in case of long electromagnetic waves. The sun causes 44% of the solar radiation is visible, 53% infrared that causes heat and 3% is ultraviolet radiation. Subsequently, the sun radiates relatively shorter waves, thus appear more red then violet. However this is only seen during sunrise and sunset, otherwise daylight is perceived as white light by the human eye. The preceding influence of daylight, thus the impact of electromagnetic radiation of the sun on human health, expresses its relevance.

Astronomical implications
The primary source of daylight is the direct lighting form the sun whatever the condition of the sky. Therefore the position of the sun relevant to the orientation of the roof is a dynamic condition of great importance to the implication of Future Field. Astronomical fundamentals, like the axis of inclination of the earth, the daily rotation of the earth around its own axis and the rotation of the earth around the sun over a period of one year all determine the impact of Future Field. In other words, the annual cycle of the earth determines the position of the primary light source. Thus, creating seasons each with its own conditions; intensive lighting and longer days during summer and darker, shorter days in winter.

The position of the earth is defined by two angles; the azimuth, \(\alpha\), and the angle of elevation, \(\gamma\). On maps the azimuth is the horizontal deviation of the position of the sun from 0°, North, around the clock with West at 270°. On a vertical projection the angle of elevation is the position of the sun over the horizon.

By the positioning of the degrees of latitude and the angle of elevation during the annual cycle, the data, the average radiation of the sun can be determined. Form this data only the visible wavelengths, or light, can be extracted and quantified. However the large amount of studies and model for determining the total solar radiation in relation to an angle there never about illumination. They mostly determine the total energy in relation to a slope, expressed in percentages. Fortunately, the percentage of total solar energy has the same relation as the total solar illuminance. Both roof surfaces of the SBC (1&2) in relation to the solar radiation are 70%.

Thus, the angle of elevation of the sun, corresponding to the time of year, can be determined for all degrees of latitude. Fortunatly the exact conditions can be determined by computer software. However, the location of the SBC is not exact; partiality in the software let too location in Amsterdam (4.50° longitude, 51.90° latitude) instead of Delft with negligible consequences’. Subsequently the daylight is a function of time and location come with greater variables namely, the weather conditions.
Meteorological features

The radiation of heat and the intensity of the sunlight on the surface of the earth, or in this case of the roof, over the course of the year are determined by the previously explained geographical latitude, time and varying conditions of the sky (clear, fully or partially clouded), in other words; the weather.

The duration of bright daylight in one year is around 4300 hours out of 8760 hours total. But, the hours of sunshine varies from location and bright daylight hours shine in a variety of intensities. Due to weather patterns and daytime the majority of sunshine occur during summer (northern hemisphere). Around 2/3 of the total daylight, sunlight that reaches earth is scattered due to weather conditions.

In the Netherlands, location of the SBC, the value of radiation is approximately 800 W/m² or 100 000 lx in intensity on a horizontal surface. The radiation power is reduced by very thick cloud to approximately 200 W/m² and 19 000 lx in intensity, and in the case of only diffuse radiation, or the sun completely obscured, it is only 50 to 200 W/m², 5000-19 000 lx. By using an average level of radiation during a day namely, an external illuminance of a clouded sky, the weather conditions are excluded from further analyses on light. The average level contains varying diffuse radiation of about 5000 lx in winter to 19 000 lx in summer. By using the general assumption that during 90% of the time between 8.00 and 16.00 the SBC is lit according to the previous requirements, Future Field will function appropriately. The remaining 10% of time is due to bad weather conditions not taken into account. During these times artificial lighting will fulfil the requirement. During these hours the illuminance of daylight in the Netherlands is 6000 lx. (Figure 28)

![Figure 28 Illuminance of daylight in relation to time](image)

(Figure 28 Illuminance of daylight in relation to time)

12 (Linden, 2000, p. 85)
**Internal daylight effect**

To measure the internal effect of daylight, a daylight factor (D) is introduced. The admission of daylight of internal areas can thus be measured and analysed. Daylight in internal areas is a ratio with is always given as a percentage. The ratio of illuminance of the internal area (Ei) to the prevailing external illuminance (Ea), where $D = \frac{E_i}{E_a} \times 100\%$. So, the illuminance of internal area varies only in proportion to the external illuminance prevailing at the time. During 90% of the time the lobby requires lighting level of 200lx (Ei) from Future Field. The previous data provided an minimal illuminance of 6000lx (Ea) on the outside. Subsequently, the daylight factor (D) can be determined:

$$\frac{200}{6000} \times 100\% = 3.3\%$$

The same formula is true for determination of the daylight factor for work areas with an requirement of 500lx (Ei) and the museum of 333lx (Ei).

$$\frac{500}{6000} \times 100\% = 8.3\%$$

$$\frac{333}{6000} \times 100\% = 5.6\%$$

The daylight factor (D) always remains factor which is influenced by many factors. There is component of light from sky (DH), an effect due to neighbouring buildings (DV) and the contribution from internal reflection (DR). Then there are reduction factors; the light transmission factor for translucent material (t), the scatter effects due to the construction of window/element (k1), the scatter effect due to the type of translucent material (k2), the effects of the angle of incidence of the daylight (k3). Where subsequently:

$$D = (DH + DR + DV) \times t \times k1 \times k2 \times k3$$

The previous analysis of the build environment proof little consequences for Future Field. This leads to the assumption that the neighbouring building have no effect on Future Field. Thus $DV = 0$. If there is no building reflection the component for the sky in case of Future Field is considered to be 1 (DH). Future Field is considered an kinetic application on the building envelope. Therefore the angle of the sun collector changes, as does the input of light from the sky (DH). Orientated towards the south at an angle of 30° will provide larger amounts of light than north with an angle of 30°. The results of the daylight factor will later be compared to this dynamic aspect.

The internal reflection (DR) depends highly on the material of the interior structure and objects. The ceiling usually influences the reflection factor the most but here it is left out of the equation. Next to the light-emitting endpoints, the ceiling is assumed black. Future Field functions as a uniformed skylight thus, have less effect on additional reflection from the ceiling. There are furthermore little wall to reflected upon because of the large open space. However, based on the amount translucent area compared to the floor space there is a hypothesis made for the additive reflection component. Therefore the assumption is made that the internal reflection (DR) with a reflection factor for 0.25, a general low average.
The additional factors of daylight are now followed by the reduction factors. The formula for establishing internal illuminance by daylight is specified for contemporary technics of window in the façade. While the basics are the same but the reduction factors apply differently.

The scatter effects due to the construction of window/element are foreseen in the light collector (k1). Although the light is mainly focused on the centre there is still dispersion left. The interior of the collector is highly reflective in order to centre as much light as possible. Therefore this factor is assumed 0.85, higher than a normal window construction (0.75).

The light loss from contamination or the type of translucent material (k2) is set on 0.7. However, the material is used twice in the technic (k2.1 & k2.2). It makes up the cape of the collector and the end-emitter of the internal part. Therefore k2 = k2.1 * k2.2, thus making the contamination for translucent material combined; 0.49 (k2).

Normally, the effects of the angle of incidence would affect the internal daylight but without a build environment the impact is zero. Therefore the angle of incident is left out of the equation with the assumption of an open field. However, the impact of an angle of incidence in case of a build environment would be as dynamic as the input of daylight itself. Future Field is considered a kinetic application on the building envelope. Therefore the angle of incident is actually dynamic as well.

The light transmission factor for translucent materials (t) is only applied in the optic fibre. It is derived from the combined reduction and absorption of the plastic fibres. In the case of Future Field it accounts for 7% per metre.\textsuperscript{13} The average length of the fibres is set on 5 metre which results in a factor 0.7 (t). Which subsequently the fibres have a 30% loss of light within the thread.

Consequently, the whole formula for calculation of interior daylight factor for Future Field is:

\[ D = (DH + DR + DV) \times t \times k1 \times k2.1 \times k2.2 \]

\[ D = 1 \times 1.25 \times 0.7 \times 0.85 \times 0.49 \]

Therefore the daylight factor at an average length of 5metres for the fibres account for D = 0.34. This results in a good impression when it is related to the total amount of solar irradiance. But firstly a daylight factor especially for the experience of motion is introduced namely, the illuminance factor.

\textsuperscript{13} Fibre Optics, p.31
Illuminance fluctuation factor

There is a minimum of perceptible change in illuminance namely, a factor of 1.5. Differences in lighting can thus be recognised if one source is one and a half more intense than another. Therefore intentional graduations in illuminance levels for internal areas have to be more than a factor 1.5. But a subjective experience in effect of graduations in illuminance is best perceived by a factor 3.\textsuperscript{14} Thus a factor 3 provides a properly visible contrast in lighting that enables an internal experience of motion. As a maximum for a subjective experience the contrast in illuminance is set on 5 to expel undesired high levels.

<table>
<thead>
<tr>
<th>Illuminance factor</th>
<th>Subjective experience of contrast</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>None</td>
</tr>
<tr>
<td>1.5</td>
<td>Visibly recognisable</td>
</tr>
<tr>
<td>3</td>
<td>Clearly distinctive</td>
</tr>
<tr>
<td>&gt;6</td>
<td>Too high</td>
</tr>
</tbody>
</table>

\textsuperscript{14} (Linden, 2000, p. 83)
Dynamic daylight illuminance factor

The following effect reveals the impact of orientation of Future Field. It is the illumination ratio according to the individual bending of the strands, the orientation of the daylight collectors. It concerns a graphical analysis based upon the previous displayed percentages of total solar radiation. (Figure 27, p.30)

There are two direction of bending, perpendicular to each other, displayed to reveal the effect of orientation. Frist bending direction is from North to south and hence the second orientation from West to East. The diagrams display an increase in the percentage of the total solar radiation when turning towards the sun and a decreasing irradiance while bending away. The percentage at certain direction must be seen as the additional, dynamic factor of internal fluctuating daylight illuminance specifically for the SBC.

The lines displayed below the total solar radiation are crossed with the illumance factor to provide insight to the required angle of bending in relation to the interior motional effect. By the analysis of the North-South direction the minimal angle of bending is -10° to accomplish a recognisable brightness in relation to the 30°, 100% radiation. Consequently, a difference of 40° in bending is required of the individual strands. A 40° radius can be foreseen but unfortunately it is the minimal angle required to establish. The North-South direction is considered as the highest fluctuation of daylight. The West-East direction, the minimal direction of bending for fluctuation in brightness, requires a 180° at 100% of the total solar radiation.
Motional behaviour

Wind conditioning
The wind can never be fully controlled but there are certain aspects that can direct it. Future Field must be in desired motion for most of the time. To achieve the motion extremes must be avoided. No wind would Future Field useless and large wind pressures can damage it. Future Field will be designed to deal with heavy winds but extreme and long exposure will have a damaging effect. There will always be extreme wind conditions like storms but the build environment will have an impact as well. The build environment can either have a damaging effect or provide sheltering for the building elements. But extreme wind conditions due the build environment must be reduced too. The shape and orientation of the building plays an important role in wind conditioning and need attention as well.

Information on weather data is based upon weather station Zestienhoven at the Hague/Rotterdam airport near the vicinity of Delft. The information is displayed in a circle containing the time and average wind speeds. From this data an abstracted version is made to point out the main issues concerning Future Field. The abstraction shows a clear distinction in the main directional wind namely, southwest. Whereas the three other directions reveal duration of around 20% with lower velocities, southwest wind exposes higher winds with a 40% attendance. Any problems due to high winds most likely come from southwest. Therefore the wind direction from southwest is analysed.
Building implication

The SBC is especially designed to withstand high wind from a southwest orientation. In the preliminary design of the SBC only the main direction of the wind and the orientation of the roof were taken into account. The roof was orientated to North-Northeast to preserve a sheltered area against large wind loads from Southwest. The sloping roofs are placed in such a way that they have protection against high wind. In effect, the wind at the sloping roof is swirling and thus come from any direction. This will have an immediate effect on the motional behaviour of the field. The swirling effect is seen in the ambition, a wheat field in motion. (Figure 4, p. 12) The form of the SBC is therefore contributing to the experience of motion. There is even the possibility that the building volumes are effective in reducing wind loads that there is little left to power Future Field. Analyses and experiments could provide better understanding. Yet the analysis also points out the significance of the roof trim. The wind loads are at the highest around the edges of the roof.
Urban implication

It is not only the size and shape of the SBC that has implications concerning Future Field but the urban context as well. The build environment of the SBC is as important as the SBC itself. Especially high building blocks can have a damaging effect the functional requirements when it comes down to wind behaviour. The effect of unfortunate wind directions, speed and height can have implication for a zone surrounding the function. Therefore this zone is shown in an urban plan which stretches around 200m from Future Field. Any obstacle outside this area will not have an effect on Future Field. However, any building that does stand in the implication zone must be examined. Thus, buildings at the south and on the east of the SBC require attention.

The buildings at the south are exactly too low to have any negative effect. But the buildings at the east are amongst the highest in the neighbourhood. If these building have a negative effect on the SBC it will most likely comes from Northeaster direction due to suction at the rear of the building. The rear of the building disturbs an area of around twice the height.
Like the SBC, the higher office buildings the wind swirls around the building especially at the rear. The effects will most likely have a possible effect on the experience of motion. However, between the buildings there is a concentration of high wind pressures that can result in a negative effect. Because the distance between the SBC and the high office block more than twice the height and the exposure does not acquire in the main direction, its influence is assumed insignificant.

**Kinetic behaviour of strands**

The material properties of Future Field have an impact on the motional behaviour of the entire field. The shape and size of the strands together with its flexibility will have the result in a certain motion. The increase in thickness can result in the desired bending effect. While the strand bent further, the thickness thus resistance to deformation increases. The result is an exponential resistance in relation to wind pressure.
CONCLUSION

Main achievements

The first phase of the design study focuses on the achievement of an ambition. The ambition recalls a metaphor of the motional effect in a field of wheat due to wind. It is a study towards a concept for the roof of the SBC which comply with the architectural and urban requirements. Thus the main research, within the context of the ambition, was asked as follows;

Research question 1.0, How can a building envelope generate an experience of motion, explicitly suitable for the SBC?

The answer can be found in the concept of Future Field. It is an architectural integrated kinetic building envelope explicitly suitable for the SBC. Future Field exists of a field flexible strands that collect daylight and transmits light inwards trough use of optic fibres. The motion caused by wind will generate different amounts of daylight collection thus making the light transition dynamically. The human experience is highly influence light and therefore the light acts as a medium to generate an experience of motion. The use of daylight also has advantages of increasing productivity and the general heath while keeping the energy demand low by decreasing artificial light. In the first conceptual design phase the aspect of electricity was introduced. But study proved the alternative production of electric energy was simple not feasible to meet the conceptual requirements. The technical innovation is regarded as too advance and exceeds building technologic studies. It is a study on it own and requires extensive knowledge in the field of electro mechanics.

While the main research problem is answered by a fundamental concept. The architectural application of the concept requires specific knowledge of its implications. So, based on the fundamental concept of Future Field a more precise research question was raised.

Research question 2.0

How can the roof of the SBC generate and maximise an experience of motion by use of daylight and fibre optics?

The experience can be maximized by quantifying the necessary illumination requirements and acting upon the outcome. The internal experience of motion is attained by an additional illumination factor introduced as the dynamic daylight illuminance factor and the Illuminance fluctuation factor. The latter factor is perceived as the difference in brightness which is recognisable by the human eye. The dynamic daylight illumination factor is the effect the direction the solar radiation collector or the orientation of the daylight input.

The standard requirements can be easily fulfilled by Future Field. Even in relation to the orientation of the strands. The minimal illumination of internal daylight exceeds its requirements. But the minimal illumination of internal daylight cannot be fulfilled in relation to the illuminance fluctuation factor. Therefore the experience of motion of internal daylight cannot be maximised to the required values.
Future work / architecture

The final concept of Future Field will be equipped with a hanging lens. The lens is placed in the daylight collector and moves due to the wind. The lens results in dynamic concentrates of light through the fibre optics. The bundles of light can answer to the requirements of illuminance fluctuation factor thereafter Future Field fulfils all its requirements.

Final concept of this design study is Future Field; a building application especially designed for the SBC. This thesis results in a concept with parameters for further architectural design. With this concept the internal area of the SBC will be designed. Lighting effects and light emitting height will be the tools for design the lobby, workspace and museum of the SBC.
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APPENDIX A

There are several experiments conducted during the design research. These experiments focused more on a conceptual level and were very basic in their setup. It does not provide hard scientific evidence but still play a crucial role within the design research. These experiments translate a more or less abstract ambition of Future Field into form. And more importantly, prove to leave an impression in its effect.

All experiments, relevant to the final design, will write down including the setup and procedure to provide a clear picture of the results and limitations of the design process. The experiments are also bundled in series because they were conducted at the same time and/or with the same intention.
Experimental series 1

Introduction & objective

The ambition is achieving similar motional effect of a field of grass to create an interesting experience. To make sure that the field of grass is the right metaphor an 'field'-experiment is conducted. By filming several interesting wind effects more or less randomly statements can be made about the concept. Analysing the result will draw up boundaries for a design. Will only a field trigger the effect or are there more options. The objective of this first experimental series is to clarify the metaphor and set a statement toward the concept of motion.

Setup & procedure

Series 1.1 and 1.2 are two of a more extensive field research. But because the results are hardly noticeable in a sequence of picture there are no more two displayed in the results. Series 1.1 are high trees within an urban environment under heavy wind conditions. Series 1.2 is a bundle of thin grass under gusting winds. Both series are filmed for several minutes. No additional measurement where taken. Among the studies that are not displayed in sequence where the following settings; fields of grass, corn and other vegetation such as a hedge.

Results & discussion

Sequence 1.1

Sequence 1.2

While the sequences show little motion it is present in the film. The movement can be considered irrational and unpredictable. The motion consists of waves formed by little or big gusts of wind, the origin of the unpredictability. But the waves and the motional effect that form the ambition of this project can be best experienced in a larger area. Trees, plums or bush do not have the same effect as an entire field.

Conclusion

The metaphor of the field is confirmed. The ambition for motion is best described as a surface area with discreet 'waves' caused by gusts of wind.
Experimental series 2

Introduction & objective

While the ambition is revealing a motional behaviour of the exterior namely in waves or field effects, the interior only speaks about light fluctuations. In order to clarify the intentional effect of the interior of the SBC, the following experiments were executed. The experiments where inspired by the precedential research on building technologic methods of movement and light fluctuations.

As stated in the conceptual design phase light fluctuations, this uses daylight as a medium, need to activate an experience of motion. Light fluctuations can either be triggered by movement in shading or movement of light ‘collector’.

The objective is to find a concept which will trigger an experience of motion. And comply with the requirements for the SBC. Results will be analysed and compared to find the best solution for light fluctuations.

Setup & procedure

Series 2 exists of three experiments. All experiments are filmed in a cardboard box with basic models to simulate an interior and provide a certain impression of scale. The experiments are filmed at least two times and each takes about 1 to 2 minutes. Because this research paper does not provide motion pictures a sequence of 5 snapshots reveal the results and the notion of time and motion.

Series 2.1 is a concept of rotating elements which reflect the light source in different directions. It consists of four rows of rotating foam models covered in aluminium for reflection of light. The rotation is trigger manually. The lighting conditions are a roof light with daylight and an additional 40WATT lamp at 1m. above the model. The reflection and shading changes will cause the light to fluctuate.

The second series 2.2 is a free moving shading element. In further design this element can consist of either vegetation or free moving building components. In the cause of this experiment a plant is used which is placed just above the model. The leaves will move because there is a ventilator operational which is placed at 1.5m. from the model. The lighting conditions are a roof light with daylight and an additional 40WATT lamp at 1m. above the model. The changing shading patterns of leaves will trigger a light fluctuation.

The third experiment is the use of a moving light collector. It investigates the interior experience of changing light intensity without shading. It is part of the idea to transmit light by using glass fibre optic technology. In this experiment the light source will fluctuate to simulate the movement of a collector. And only the interior effect of fluctuating light transmitting will be investigated.
Results & discussion

Sequence 2.1

Sequence 2.2

Sequence 2.3

Series 2.1 resulted more in a variation of shading patterns than reflections, and concentrated bundle of daylight the fluctuate. This effect is only experienced on the exterior of the building. The shading itself has a concentrated point and 'flickers' light just around rotational element. And a more subjective feeling of an impression is absent. The effects in the 'room' is not attractive enough and do not really appeal to an experience of motion. Series 2.2 resulted in a likeable effect; it triggers an experience of motion. But the shading effect does not really comply with the concept of the SBC. It cannot be seen as a technical innovation, required for the architectural assignment. When compared with series 2.3, the effect of motion can be seen dull or too simple. Somehow a bundle of light has a more dramatic effect than shade. The argument here is subjective but none the less an empirical observation. Series 2.3 does not provide a sufficient idea of experiencing motion. It is prove that transmitting light is an option but further study is necessary.

Conclusion

Series 2.1 does not comply with the concept because it lacks the experience of motion and leave little impression. Series 2.3 is appealing and trigger an experience, but not yet the experience of motion. It is prove that transmitting light can be seen as an option but further study is required. If further experiments within the idea of a moving collector and transmitting light are positive, the concept is successful. If not, series 2.2 can serve as an alternative for the concept of motion yet the experience of motion is not very intense. The concept of inspiring the people at the SBC is not likely to be high.
Experimental series 3

Introduction & objective

Experimental series 3 reveal a potential for the experience of motion by transmitting light. The experience is positive yet the idea of motion is lacking. The concept can be seen as a technical innovation and is likely to provide an inspiration in the field of technology.

To investigate the potential of experimental series 2.3 the following series 3 is conducted. Again, the focus lay on the interior experience of motion and will clarify the intentional effect of the SBC. The experiments where inspired by the precedential research on building technologic methods of movement and light fluctuations.

As stated in the conceptual design phase light fluctuations, this uses daylight as a medium, need to activate an experience of motion. Light fluctuations in this series will focus on a moving light ‘collector’ and transmitting light through fibre optics. Preliminary to the experiments two earlier models visualized the use of fibre optics namely; picture x.x and picture y.y.

The objective is to find a concept which will trigger an experience of motion by using light transmitters. And complies with the requirements for the SBC. Results will be analysed and compared to find the best solution for light fluctuations.

Setup & procedure

Series 3 exists of two experiments. All experiments are filmed in a cardboard box with basic models to simulate an interior and provide a certain impression of scale. The experiments are filmed at least two times and each takes about 1 to 2 minutes. Because this research paper does not provide motion pictures a sequence of 5 snapshots reveal the results and the notion of time and motion.

Series 3.1 is a model which exists of Plexiglas strands, 5mm thick. The strands are cut in several heights. It gives an impression of the lighting conditions at different heights while simultaneously investigating the idea of using Future Field as an instrument of form within the SBC. To mimic motion in the strands, a flashlight is moved just above the model. Next to the flashlight a lamp of 40 Watt is placed 1m. above the model the provide the remaining daylight.

The second series, 3.2, has a similar setup but in a smaller scale. The strands are half a millimetre, exists of plastic and is flexible. Again, it gives an impression of the lighting conditions at different heights while simultaneously investigating the idea of using Future Field shape the interior of the SBC. There is no need for a flashlight because the strands are flexible. Light fluctuations are generated by the movement of the strands, just like the initial thought of a moving light ‘collector’. The movement of the strands is caused by a ventilator which is placed at 1.5m from the model. The lighting conditions are a roof light with daylight and an additional 40WATT lamp at 1m. above the model.
Setup 3.2

Results & discussion

Sequence 3.1a

Sequence 3.1b

Sequence 3.2

Series 3.1a gives a great impression of the concepts ability. The lighting effects are successfully dramatic but because of the extreme bundles of light, the contrast is far too extreme to be applied in the SBC. Series 3.1b has additional lighting of 40 Watt that soften the contrast in the 'room'. At these lighting conditions the concept can be proven applicable. The experience of motion is there together with an ambiance of technical innovation. While the effect of series 3.2b is successful, the scale is not. The strands are far too bigger in comparison with the 'room' and its models. It is more a forest of individual strands then it is a field as a whole. Future Field as an instrument of form, shaping space, has a similar result. The potential is high but in a different, more appropriate scale. Compared to series 3.1, 3.2 show a more appropriate scale. This scale can be used to shape the interior of the SBC. The lighting intensity on the other hand is not sufficient. There is too little light transmitted to light up the interior. Because the scale same more appealing the light is not. Increasing the amount of strands will likely be enough. The lighting effects are reasonably good and provide an interesting experience of motion.

The lighting effect at different heights in the 'room' is similar for both series. The bundle of light is mainly focuses at the end of the strand and can therefore be seen as a light point. A light point of daylight. The intensity of the light is, among other things; depend on the distance of the light point. This can be used as a parameter for the SBC's architecture.
Conclusion

While 3.1a show the capability of experiencing motion, 3.1b is a more applicable lighting effect at which the internal areas of the SBC can be lit. But because of its large scale the series is not applicable. Series 3.2 on the other hand proof to cause on experience of motion and comply with the architectural demands of a technical innovation. Therefore the concept of transmitting light through fibre optic is successful. Furthermore an additional parameter for architecture can be investigated; Future Field as an instrument of form and the use of different light intensities by the changing the light point heights.
Experimental series 4

Introduction & objective

The result of the conceptual design phase is, from the upper side of the design, a simple abstraction of field of grass. The aim is to mimic the motional effect of the field so further likenesses can be successful to. Analysis of the field of wheat used to express the ambition provide specific attention towards the endpoint of a single straw. It appears thicker and exists of hair like plums. In effect the 'head' of the straw will absorb more wind in the upper region then at the base.

The objective of the following experimental series is to prove if, and how much the strand move more with a 'head' then without. Possible result will express the necessity of a 'head' for the strands, or not.

Setup & procedure

Series 4.1 is a small scale model of two methods at the same time. There all flexible plastic fibres divided into two groups; with and without 'heads'. The 'heads' of the group of fibres exists of dried glue droplets. The models are exposed to ventilator at one metre distance. The series is filmed for a distance of 50cm for several minutes.

Series 4.2-4.4 are three experiments with metal threads that simulate the strands of Future Field. Four threads, a meter high, are fixed to a wooden base and exposed to wind pressure. All three series are equipped with different endpoints. One is without a 'head'. A cotton wool ball of 15mm makes up series 4.3. And series 4.4 is prepared with the cotton ball and light weight foam straws to mimic the wheat over a length of 30cm. These experiments were conducted in the outdoor environment, on top of a roof. The experiments will be exposed to actual outside wind conditions. They are filmed for several minutes for a distance of 2metres.
Results & discussion

Sequence 4.1

Sequence 4.2

Sequence 4.3

Sequence 4.4

All sequences show little motion but the actual motion it clearly visible in the recordings. The movement can be considered irrational and unpredictable. And both experimental setups show a wide and clear motion of strand with a 'head' then without. When the experiments are looked closely they have a likeness in movement of strands without a 'head'. Instead of bending and swaying it only vibrates extensively at the endpoints. The series 4.4 compare 4.3 a larger motion. But the difference between the vibrations of 4.2 and the swaying of 4.3 is considerably better visible. Notability, the sequence 4.4 visualizes a movement that is more uniformed. One strand will exactly mimic another strand because the 'heads' of both are intertwined. Eventually resulting in a motional effect of a stiff surface rather the in 'waves' mentioned in the ambition.

Conclusion

Both experimental setups reveal the necessity for a 'head' at the endpoint of the strands. However, the size of the 'head' does not have to mimic the straw of wheat. Instead, the required motion can be achieved by a smaller and simpler shape of the endpoint. A larger and expressive 'head' on the endpoint will only result in a stiff surface rather than a dynamic building envelope. Therefore, experimental series 4.3 will be a more successful activator of an experience of motion then other methods.