

Stelvio

A novel hands-off approach to design of Settlements as self-organizing systems of growth and decay

Martin Ebensperger

University of Innsbruck

martin.ebensperger@student.uibk.ac.at

Günther H. Filz

University of Innsbruck

guenther.filz@uibk.ac.at

Abstract

“One must study not only finished forms, but also the forces that moulded them: the form of an object is a diagram of forces” (Thompson 2006).

In the field of architecture and urban planning “settlement” usually refers to planned, organized and finally realized buildings and infrastructure that are superimposed on the (natural) environment by man. However, the history of civilization knows innumerable unplanned settlements. Today we are learning from what was criticized for its seemingly inefficiency, chaos and sign of developing countries. Simultaneously, we are coming under increasing pressure to find sustainable solutions for our built environment and therefore look into examples and systems of nature.

This paper presents a hands-off approach to design, to create settlements as self-organizing systems of growth and decay in a conceptual way. The focus is on a new methodology of settlement planning which is not static, while the traditional understanding is linear, top-down regulated and control-based. Our starting point is the definition and digital simulation of predominant parameters including solar analysis, erosion from the water flow, wind speed, wind pressure and wind suction on objects, growth and decay. Strongly affected by climate change, the extreme alpine region from the valley to the Stelvio Pass at an elevation of 2,757m above sea level in South Tyrol, Italy, serves as a case study. The results of our initially separate simulations usually show processes of transformation to constantly adapt to landscape topography, to climatic conditions and physical laws. Stepwise, our simulations are overlaid, merged, tested, observed and evaluated on a representative test field. We observe the growth but also the decay of inhabitable structures in cycles up to more than 300 years, by looking into the effects of changing parameters in the context of the specific landscape. Our investigations focus on several scales from macro scale, the landscape, to meso scale, the settlements, to micro scale, the buildings their materials and surfaces. The results suggest unthought forms and structures of settlements and buildings that cyclically reshape and reorganize the landscape in a nature-compatible way by influencing erosion, redirecting water and purifying airflows, but also integrate and adapt to the natural environment.

Keywords: unplanned settlements, self-organizing systems, sustainability, architecture, simulation, growth and decay.

Self-organizing systems in an architectural context

How do settlement forms and structures cyclically reshape and reorganize the landscape and influence physical laws as they integrate and adapt to the environment? In architecture, settlements are considered planned. They are organized and ultimately realized urban structures. At the same time, the history of civilization knows innumerable unplanned settlements (Schaur 1992). However, complex systems consist of a multitude of individual components whose interaction with each other can lead to new results. In urban planning, self-organizing phenomena are used to describe the formation, growth and change processes of settlements (Krausse et. al 1994). New results can be achieved with the help of nature's form-finding processes (Schaur 1992). Planners' interests in the nonlinear is related to a world that is fluid and in a constant process of discontinuous change. Such a nonlinear world involves processes that can be called self-organization. Planning is the science of a purposeful intervention, usually of humans. Self-organization is a phenomenon of spontaneous order (DeRoo 2016). Biological systems typically create selforganizing forms, which are generated by physical parameters and which offer a whole world of patterns, which we perceive as irregular and complex. At the same time we can read the form as an equilibrium following its principles of genesis (Filz 2013). Nevertheless, it is even more important to understand that these phenomena can be used and influenced by human intervention (McHarg 1992).

If we consider planning less as a creative and artistic activity such as architectural design, but as an activity that sets boundary conditions with infinite possibilities of combinations within, it may allow people rather to discover and explore within these boundaries than actively design. In other words, self-organization processes respond to attractors, and the boundaries set by planners can be such attractors. To a certain extent, we will even be able to initiate self-organization processes ourselves (DeRoo 2016).

The design possibilities in architecture have mostly adapted to aesthetic and functional purposes. New disciplines include mimicry and inspiration from the complex mechanism found in nature (Benyus 2020). This opens up a new way of looking at nature. It is not about what can be taken from nature, but about what we can learn from nature (Rao 2014). It is not necessary to adapt the design of nature, but to think about how such effective functions of nature can be used. This is a radical alternative to today's industrial progress, based on a better understanding of natural systems (Hargroves and Smith 2006). Planners may be able to relate to self-organization, understand its processes, and think about whether to interfere, leave it as it is, or even change its path and perhaps transform such processes for their own benefit. Planners could strengthen their commitment to the built environment by allowing change to occur not only according to a controlled and predefined plan, but also in a "natural", uncontrolled way (DeRoo 2016). This approach is quite unusual for architectural designers, as they are educated to be in control of the design with a focus on the designs' shapes. In the world of selforganization and therefore unplanned the designer's task consequently is not to master form but to master boundary conditions in a meaningful way.

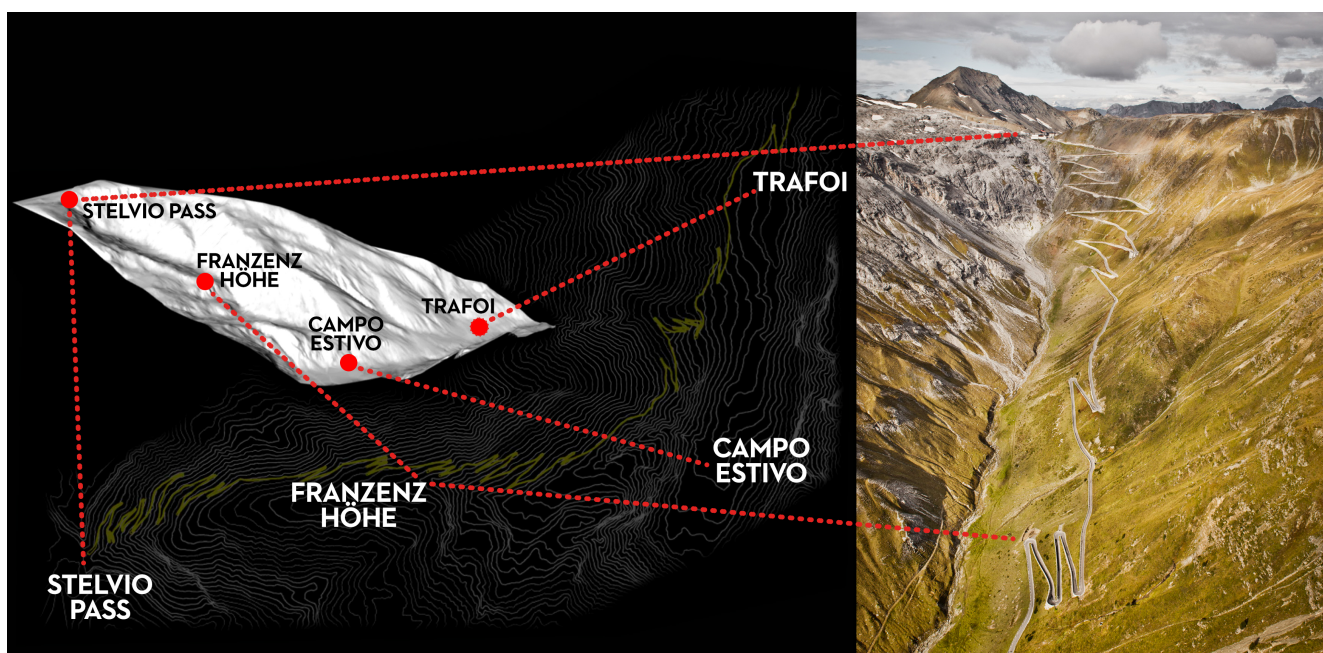
This paper presents a hands-off approach to design, to create settlements as self-organizing systems of growth and decay. The approach has been applied to a specific site and case study with the potential of being modified for other locations on our planet. It concerns a conceptual design thinking strategy (Filz et al. 2021) rather than a directly realizable planning procedure. Thereby the definition and digital simulation of predominant parameters is important, including solar analysis, erosion (SWAP / AADRL 2012) from the water flow (Ryan 2012), wind (Ibrahim 2020), pressure and suction on objects, growth and decay. As a means of design methodology, these parameters are used to explore and visualize their mostly nonlinear processes and effects on the natural, but also built environment.

Strongly affected by climate change, the extreme alpine region from the valley to the Stelvio Pass serves as a case study for a novel hands-off approach to design, with settlements emerging as self-organizing systems of growth and decay.

Stelvio , a highly diverse and extreme test field

Stelvio, short for the Stelvio region and the Stelvio Pass is a "vertical landscape" in the Alps. For its extreme conditions, explained in more detail below, this natural and simultaneously human-shaped landscape serves as an ideal test field for our investigations. The extreme alpine region from the valley to the Stelvio Pass at an elevation of 2.757 m above sea level in South Tyrol, Italy is geographically located at 46° 31' 42" N, 10° 27' 12" E, and is named after the village of Stils. The use of the Stelvio Pass dates back to the Bronze Age. However, construction work for a road started only in 1820 and ended in 1825 after 21 months of construction. Numerous hairpin turns had to be made, 48 on the east ramp and 34 on the west ramp. Most of the buildings in the higher part of the pass were destroyed during World War II, including hotel buildings (Bruns 2002). Today, the most noticeable features on the pass are the numerous snack and souvenir stands. The fortress in Gomagoi is considered the entrance gate to the Stelvio Pass. However, the road already begins in Sponding at the Hotel Post Hirsch. Along the route to the Stelvio Pass is the Franzenshöhe mountain hotel, from where the heart of the road begins. On the pass itself, there are several other hotels, kiosks and cafés, plus a chapel and a bank branch (Bogner and Baedeker 2017). Mighty north-facing glaciers mainly dominate the area around the Stelvio Pass. The valleys are covered by glacial moraine debris. Medium-textured soils are characterized by meadows, while the slopes are dominated by coniferous forests. Typical landscape features have been shaped over time by influence of weather, ice and water. Vegetation forms the basis for ecosystem function. Plants provide habitat and food for animals (Carro and Pedrotti 2011). In the Ortler area, which includes the Stelvio Pass, precipitation is low on average. This is due to the high mountains. However, temperatures at the Stelvio are often very low, even well below -20°C. In the summer months, average values of 10°C are usually not exceeded. Strong wind speeds with average values of 50 km/h are not uncommon at higher altitudes. Abundant snowfall is also recorded at higher elevations, where the total snowfall can even exceed 7 m (Carro and Pedrotti 2011). Due to the effect of rising temperatures, precipitation in winter will tend to fall as rain rather than snow in the future. Basically, snowfall is expected to start later than in the past and snowmelt will start much earlier, which will ultimately shorten the duration of snow cover. The retreat or disappearance of glaciers will have devastating consequences for the water balance throughout Europe. If this does not change in the future, it will also have a negative impact on the Alpine ecosystem (Zebisch 2018).

Figure 1. The Test Site. 3D model of the terrain and contour lines with the existing settlements and the street to the Stelvio Pass. Foto: Stefan Bogner, Nordrampe.



A study on the dynamics of natural phenomena

In order to create a self-organizing system, various parameters are used, which are dynamic natural phenomena. These ultimately determine the location, form and organization of this system. The initial separation of the parameters and studies delivered more comprehensible and easier to evaluate results to our studies. The parameters were gradually tested on the natural landscape of Stelvio, on geometric shapes and the combination of single shapes and ensembles that we implemented into the landscape. For the clarity of effects and results, principle shapes such as spheres and cubes were used in the early stages. Later the parameters and findings were overlaid, merged, evaluated and finally combined into a complex investigation, which is then exemplified with case studies.

Selected parameters and their inter-/coaction as methodological basis

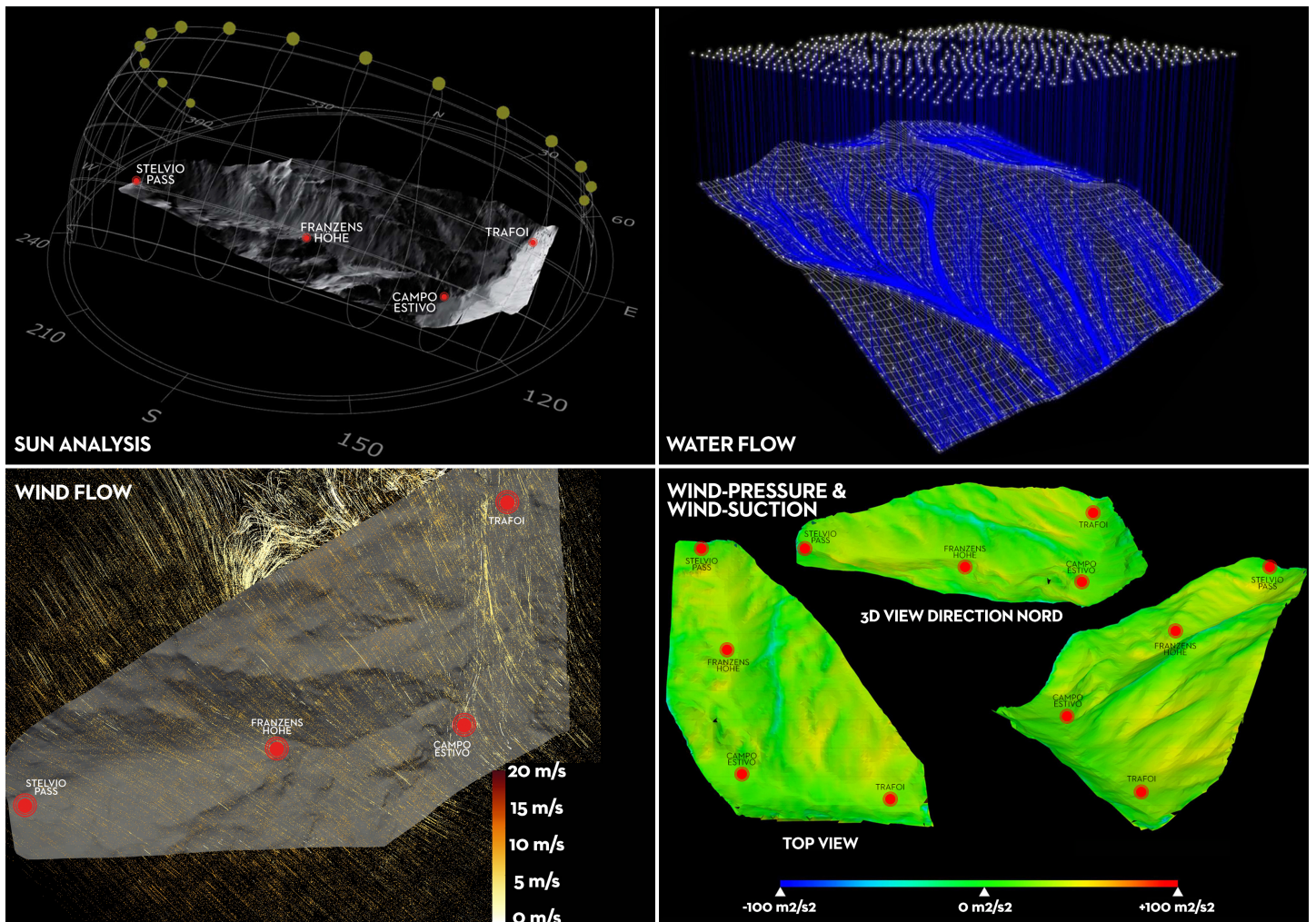
Sun. A solar analysis and the resulting play of light and shadow was used as a first parameter of our investigation. For this purpose, the geographical data of the desired solar path are defined and representative times and dates such as the summer solstice are determined. For the solar path simulation and analysis Rhinoceros 7 (McNeel, 2010), was used as software, and as a result the hourly data have been overlaid with each other. This investigation is then used to narrow down potential locations for desired settlements (Figure 2a).

Erosion. The erosion process, which constantly reshapes and thus changes the terrain, is primarily based on the natural flow of rain and melt water. Weather data of the last 100 years have been used for this study. Due to the lack of accurate weather data for the specific location of the Stelvio Pass (Carro and Pedrotti 2011), the weather data of the Monte Maria (46° 42' 22,19" N, 10° 31' 14,39" E) was used, which is geographically very close to the Stelvio Pass and therefore assumed as representative. The data used are monthly and annual precipitation data in mm. The number and distance of steps the water travels, have been defined in Anemone (Zwierzycki 2015), an application for Rhinoceros Grasshopper, so that the flow velocity could be simulated. The steeper the slope of the terrain, the larger the steps and vice versa. For the manipulation of the terrain an angle is given. That angle, which results from the groove formation was taken from the angle of repose. For our studies, gravel was used for the manipulation, resulting in an angle of 40° (Technische Universität Dresden 2021). This investigation was carried out in Bison (bisonla 2020) for Grasshopper. Since the beginning of industrial agriculture, drastically high erosion rates have been achieved. These rates can reach values of up to 90 t/ha/a. With an estimated storage density of 1 g/cm³, this translates into a loss of 10,000 tons of soil material per hectare and corresponds to a removal of soil by one meter (Schack – Kirchner 2005). Therefore, the flowlines in the project are lowered into the ground by 9 mm per iteration, which corresponds to one year. The Hjulström diagram illustrates the relationship of grain size and flow rates required for erosion and sedimentation (Schack – Kirchner 2005). The simulation of erosion shows that the terrain sometimes erodes more and sometimes less, depending on the intensity of precipitation. The results of the simulations indicate that erosion proceeds much faster in steep terrain than in flat terrain. In places where more fall lines converge, that is, where more water runs down the slope, the terrain is altered more than in places with fewer fall lines. Consequently, more fall lines result in a stronger change of the terrain in our erosion study (Figure 2b).

Wind. The wind that prevails in the region around the Stelvio not only helps to identify sheltered places, but it also represents an important parameter in the shaping of possible objects in our study of exemplary settlements. Our analysis is based on a wind rose to determine the main wind directions. From the wind rose of Bolzano, which is exemplary for the whole of South Tyrol, one can deduce

that the main wind directions are from the southeast and from the northeast (Carro and Pedrotti 2011). However, the wind speeds of Bolzano are not representative for the Stelvio Pass, due to altitude and exposure. For this work, a wide variety of wind speeds were used, originating from meteoblue, a database of precise, long-term metrological data in dependence of the geographical location (meteoblue 2021). Wind speed up to 14 m/s and more, are not uncommon on the Stelvio Pass (Carro and Pedrotti 2011). Our wind analysis is performed using a digital wind tunnel, in which all terrain and objects are defined. The simulation of the wind tunnel tests was performed with Eddy 3D (Kastner and Dogan, 2021) and post-processed in Paraview (Ahrens et al. 2005). Based on vertical and horizontal sections, it can be determined in this wind tunnel that the wind becomes weaker near the terrain and as it, progresses further into the valley. In particular, turbulences occur in dependence of the roughness of the terrain and objects and most frequently at sharp edges (Figure 2c). Wind pressure and wind suction as a result of wind forces act on the terrain, but also on the objects in the terrain. These effects are again visualized using Eddy 3D and Paraview. This study operates with the kinematic pressure given in m^2/s^2 and not with the static pressure. Low suction forces are displayed for wind from southeast at a wind speed of 20 m/s. However, if the wind comes from a northeasterly direction, an increased suction effect (about $80 m^2/s^2$) on the mountain peaks is noticeable as shown in Figure 2d.

Figure 2a, 2b, 2c and 2d. The Parameters. Sun Analysis, Water Flow, Wind Flow, Pressure and Suction.



The influence of objects on the dynamic natural phenomena

Each object placed in the landscape has direct and indirect effects on its surroundings. Apart from visual and design aspects, objects microclimatically influence their surroundings and are of course themselves exposed to environmental conditions as objects and as an ensemble. Principle studies with simple primary forms such as the cube or the sphere were used to investigate the influence of these forms on the terrain and themselves. Spheres and cubes have almost opposing geometrical features and effects, providing the chance to study for examples shapes with sharp edges and rounded shapes exposed to wind. The cubes in our simulations have a size of 30 x 30 m, the spheres have a diameter of 30 m and can thus be compared with an average size of buildings. We placed them in different arrangements and also in different locations in the terrain, in steep terrain, in flat terrain, and also on top or behind hills or in valleys to study again the response of the different parameters applied. The main focus was on the following questions: How are water and wind deflected in the process? Are there increased changes in the terrain? Do objects possibly protect parts of the terrain? Where do the natural forces have the strongest effect? Later the insights of these experiments, applied to representative sections of the terrain and landscape of Stelvio, were implemented in the growth and decay scenarios.

The erosion process was again analysed by use of the software applications Anemone (Zwierzycki 2015) and Bison (bisonla 2020). According to the weather data, the average precipitation is 676 mm per year. The average deepening per year is 9mm, which means 90mm after ten years or 900mm after 100 years. Our simulation results demonstrate that next to cubes, depressions, grooves and washouts become deeper very quickly and almost exponentially (Figure 3a). This effect occurs due to the merging and concentration of fall lines. Additionally, erosion also progresses faster in steep terrain than in flatter terrain. The longer this process continues, the more water is drained away via the grooves that have already formed which increasingly amplifies this effect. New rills are hardly added, not even by further precipitation. The influence of heavy rainfall is also only visible to a limited extent, as these are one-time events. The sum of precipitation events provides a much clearer result, although heavy rain is certainly noticeable over time.

The influence of spheres produces similar phenomena as that of cubes, albeit in a lesser intensity. The water is better distributed along curved shapes of the spheres and is directed past them. Protected areas are created in front of the spheres. This phenomenon becomes more evident as more time passes. Deeper indentations can be expected at the intersection curves of the ground and the spheres (Figure 3a). In an annual comparison, these deepening are hardly measurable. After 40 years, however, the grooving on the edges of the objects is clearly visible and can sum up to 448 mm on the intersection curves of the ground and the spheres and 512 mm on the edges of the cubes, while 360 mm are measured in open terrain.

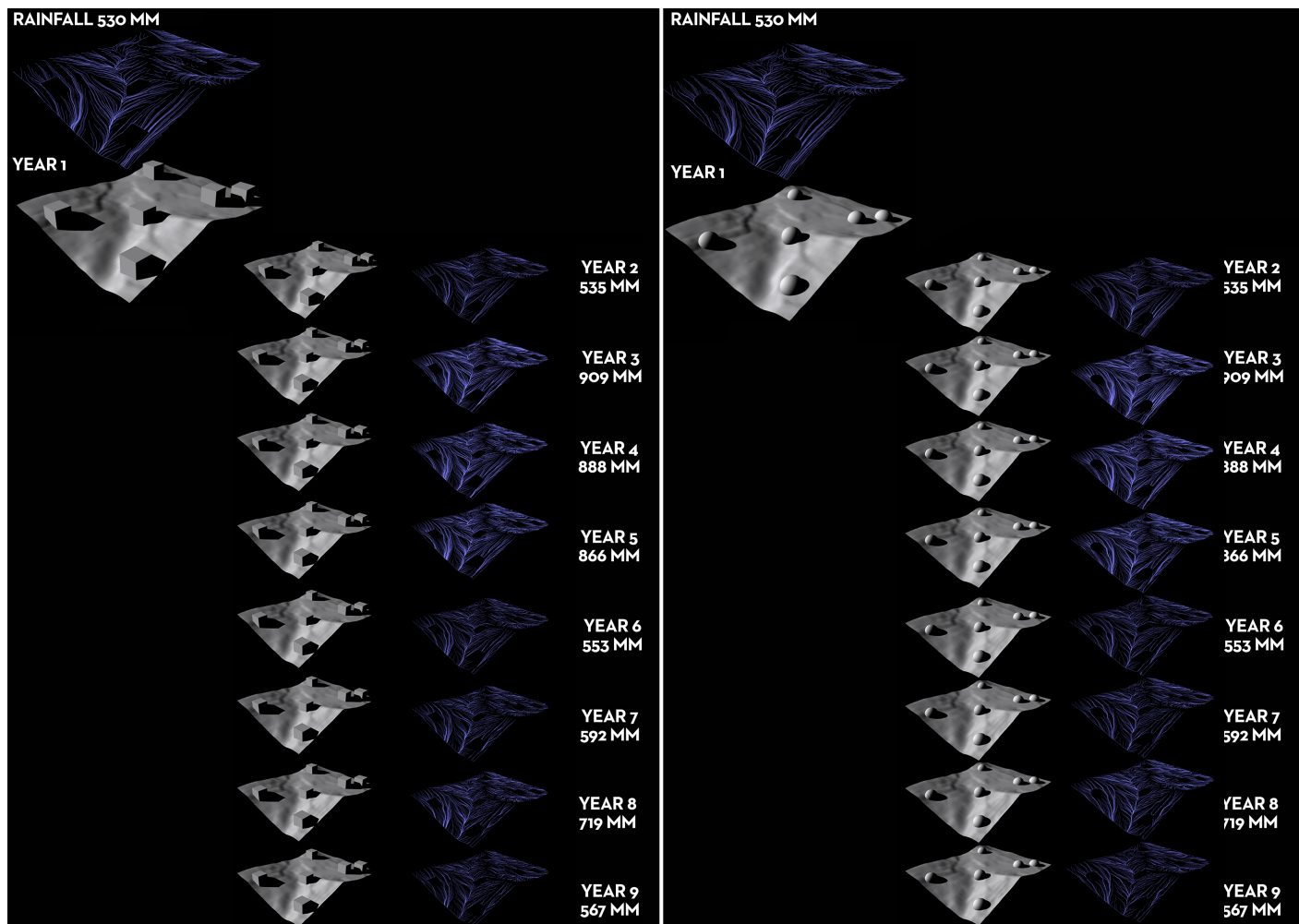


Figure 3a. The erosion process. Example of the erosion process under the influence of cubes and spheres over a period of 9 years.

The wind analysis again performed with the help of Eddy 3D and Paraview, shows that strong turbulences occur at angular shapes. As expected, the spheres deflect the wind smoother due to their aerodynamic shape. However, with the help of these analyses it is possible to find out which shapes have which influence on the wind flow depending on their position in the terrain. As shown in figure 3b, the wind is lowered from a wind speed of 5 m/s to about 2 m/s before it hits the geometric bodies of the cubes. Behind the cubes, a larger or smaller slipstream is formed, depending on the wind speed. Relatively strong turbulences are generated behind the cubes. Their intensity depends on the strength of the wind and the angle at which the wind hits the objects. In contrast to the cubes, the wind flow above the spheres is accelerated again after it has decelerated (about 5 m/s). A slipstream is visible behind the spheres, although not to the same extent as with the cubes. It is clear that the spheres cause less turbulence than the cubes due to their geometry. The wind is smoothly deflected around the spheres (Figure 3c).

The analyses of wind pressure and wind suction also show clear differences for the different geometric objects. In particular, the sides of the cubes facing the wind are those on which the greatest wind pressure is exerted. For a wind speed of 5 m/s, this corresponds to about 45 m²/s² in our simulations. In contrast, all other faces are only very slightly affected, as shown in figure 3d. The spheres, in contrast to the cubes, only experience a wind pressure of about 30 m²/s² under the same boundary conditions. Here, only punctual areas of the surface that are orthogonal to the wind are more affected, not least because of the aerodynamic

shape of the spheres. The largest wind forces manifest themselves in the form of wind suction. These forces are visible on all areas of the objects, but with $270 \text{ m}^2/\text{s}^2$, they occur most strongly in the areas of corners and edges, where sudden stall occurs. Again, the angular shape of the cube is more affected than the sphere as figure 3d shows.

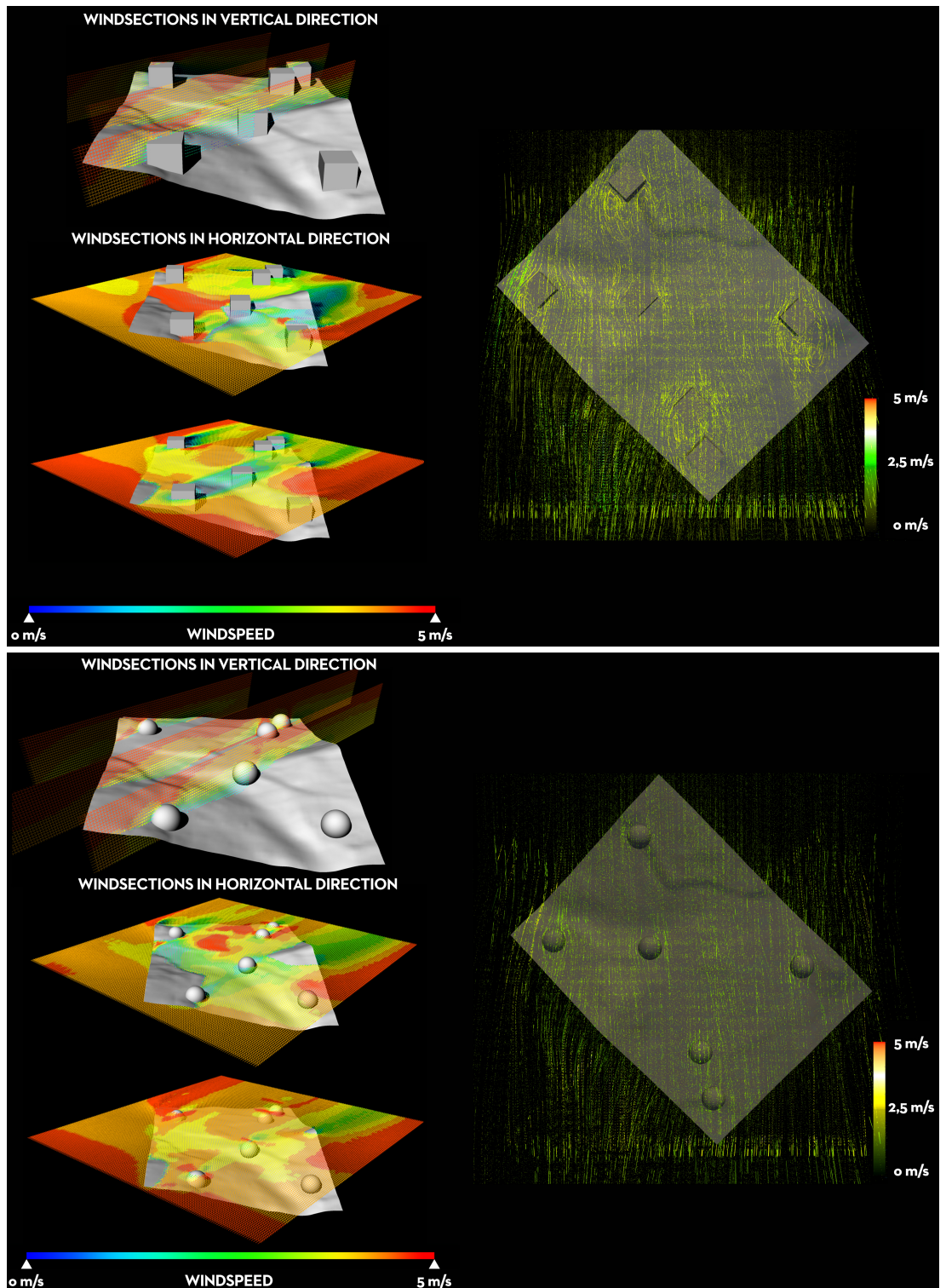


Figure 3b and 3c. The wind analysis. Example of the wind analysis with vertical and horizontal sections, as well as the streamlines.

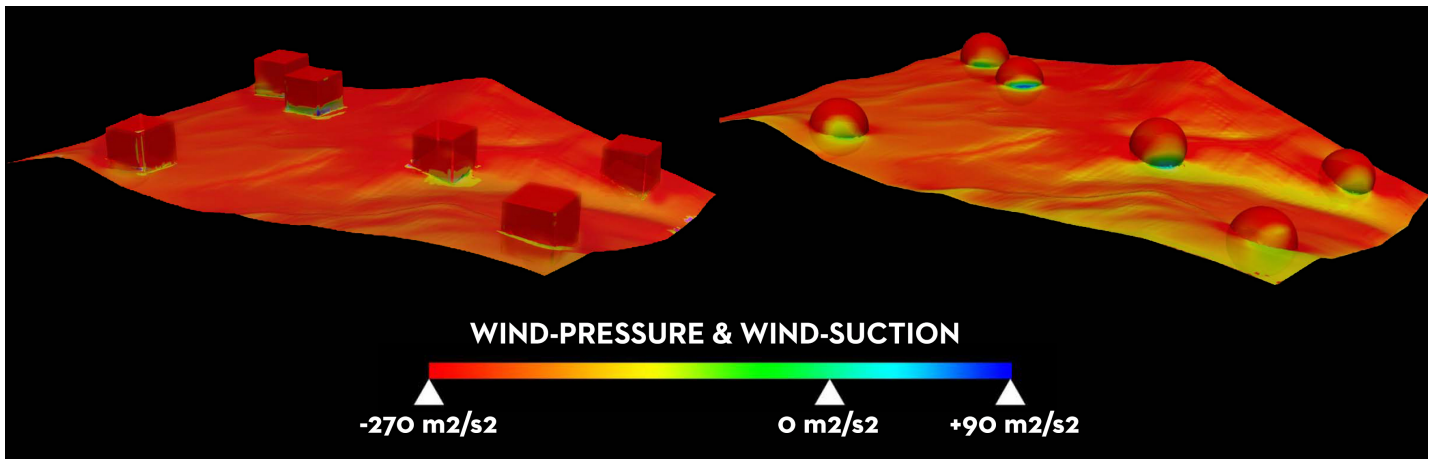


Figure 3d. Pressure and suction. Example of pressure and suction under the influence of cubes and spheres as a result of the wind forces.

Merging parameters to form an interdependent system: applied case studies in the light of time and seed of settlement

In the following, we show how the separately analysed parameters including sun and shade, erosion, wind, wind pressure and wind suction, growth and decay are combined and how they are interdependent. We explain the use of an agent-based modelling of structures and settlements associated to plant growth and how to determine the starting points (seeds) of settlements. Finally, we show the effects of where the growth is initiated. At this point the authors would like to emphasize the unusual aspect of our approach to architectural design and settlements. We reconsider self-organizing phenomena to initiate and describe the formation, growth, change processes and decay of settlements. We are aware that the parameters that we considered so far are the most basic ones and can be further complemented. As clearly observable in figures 5b, 5c and 5d, the emerging shapes are highly depending on the initial placement and origin of the process. For this reason, we are describing but not evaluating the outcomes of two opposing scenarios and the matter of time, since our simulations cover timeframes of up to several hundred years. We are also not proposing or setting up rules, but we show principles that can serve a better understanding of the proposed approach. The “final form” is a result of the interaction of parameters and time, it can be understood as a diagram of the self-organizing process, emerged not from the artistic creativity of the designer but purely from the process. However, we assume that there is no final result but snapshots of a process in time proposing resilient organizational patterns of settlements with architectural qualities.

Sunlight and shade principally define settlement areas, while erosion constantly changes and reshapes the terrain, which in turn affects light and shade. In addition, water flow determines the starting and ending points of growth curves. Wind in direction and strength, as well as its effects in the form of wind pressure and wind suction, determine settlement areas, but most importantly the shape of buildings - angular or round-, their orientation and arrangement. Growth and decay determine the development of settlement structures down to the forms of individual buildings in detail. This in turn depends on light and shadow and the fall lines of the water. The combined system of merged and interdependent parameters was applied as before to the opposing scenarios shown in Figure 4.

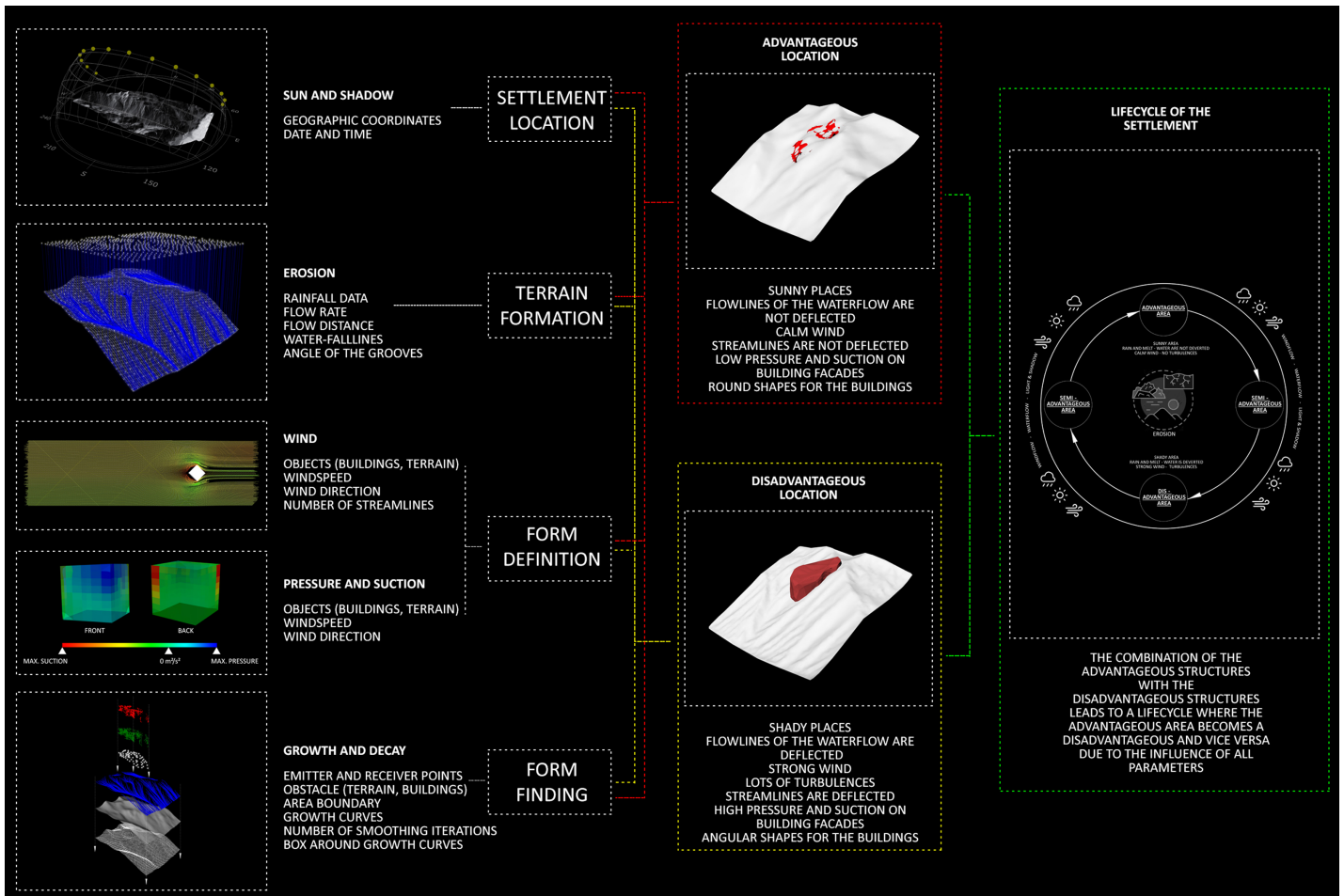


Figure 4. Lifecycle of the settlement. Graphic showing the link between the parameters and the resulting lifecycle

Plant growth: an agent-based modelling of structures and settlements

As mentioned above, in architecture, settlements are usually considered planned, organized and ultimately realized urban structures. Since our civilization knows innumerable unplanned settlements (Schaur 1992), nowadays, we reconsider self-organizing phenomena to describe the formation, growth and change processes of settlements (Krausse et. al 1994) and to achieve new, maybe more resilient organizational patterns of settlements. What all human settlements have in common is the reasoning that includes physical and socio-economic factors as well as its speed, respectively its growth rate (United Nations 2018). Today we are learning from what was criticized for its seemingly inefficiency, chaos and sign of developing countries. Simultaneously, we are coming under increasing pressure to find sustainable solutions for our built environment and therefore look into examples and systems of nature. While cities are usually considered planned and in this regard as not natural, informal settlement is a practice of adaptation to the forces of real urban conditions such as available land, transit networks, employment markets, threats of demolition, planning frameworks, local politics and climate among others (Dovey et al. 2020). According to (Dedes Nurgandarum and Mohammad Ischak 2019) city design, as a continuous urban place transformation process, emphasizes the process rather than the product, therefore to understand the physical characteristic of a settlement should be based on an understanding of its formation process. Since our research and case studies are aiming for conceptual design thinking strategy (Deo et al. 2020; Filz et al. 2021) rather than a directly realizable planning procedure, we found strong analogies to the speed and patterns of the growth and decay of plants. Our digital

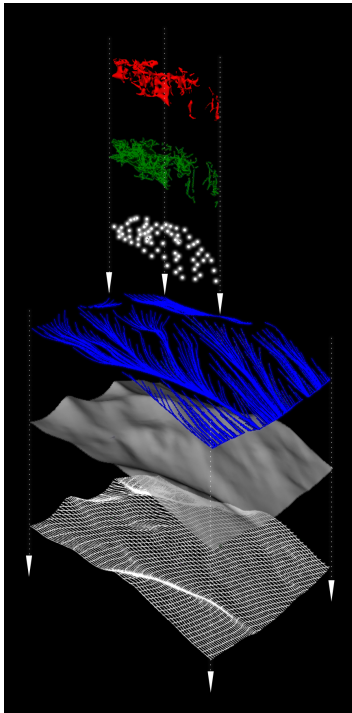


Figure 5a. Settlement growth. Different steps of merging the parameters.

simulation is generated using Physarealm (Yidong 2017), which is a grasshopper plugin for agent-based modelling based on Physarum Polycephalum. It is a stigmergy algorithm similar to ant colony algorithm. Physarum polycephalum is a slime mould, and has been used as a model organism for many studies involving amoeboid movement and cell motility (Ma and Xu 2017).

As a first step, we limited the expansion of growth to specific areas with opposing characteristics and to the structure and shape of the settlement itself. In this stage also the inter- and coaction with other phenomena were cancelled out. In this context, settlement boundaries are determined by the solar analysis, and the wind dictates whether the structures are either round or angular in shape. However, the growth is basically associated to water flow, which dictates from where the settlements start to grow. Based on these settings, the system remains self-organizing (Figure 5a). All shapes are voxel based and smoothed in advantageous locations by using Chromodoris (Newnham 2016), as shown in figure 5b. In contrast, the shapes in unfavourable location, are more compact and angular (Figure 5c). In both cases, the envelopes are dependent of the growth curves that emerged.

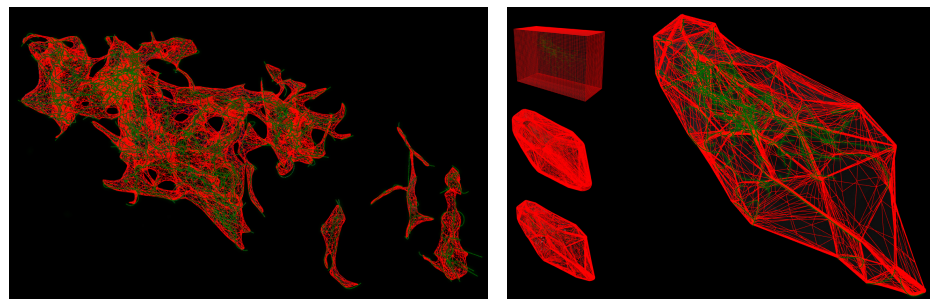


Figure 5b/c. The shapes of the settlements. Round shapes for the advantageous structure, angular shapes for the disadvantageous structure. In both cases, the envelopes are dependent of the growth curves.

Unlike the round shapes, the angular shapes seal the ground. The rounded structures are situated between the fall lines, while the angular structures sit directly in the fall lines. Early growth studies, as illustrated in Figure 5d, show the comparison of the two scenarios. However, the terrain does not yet change due to erosion. Thus, the settlements always remain at the selected location because the light and shadow play of the solar analysis does not change (Figure 5d).

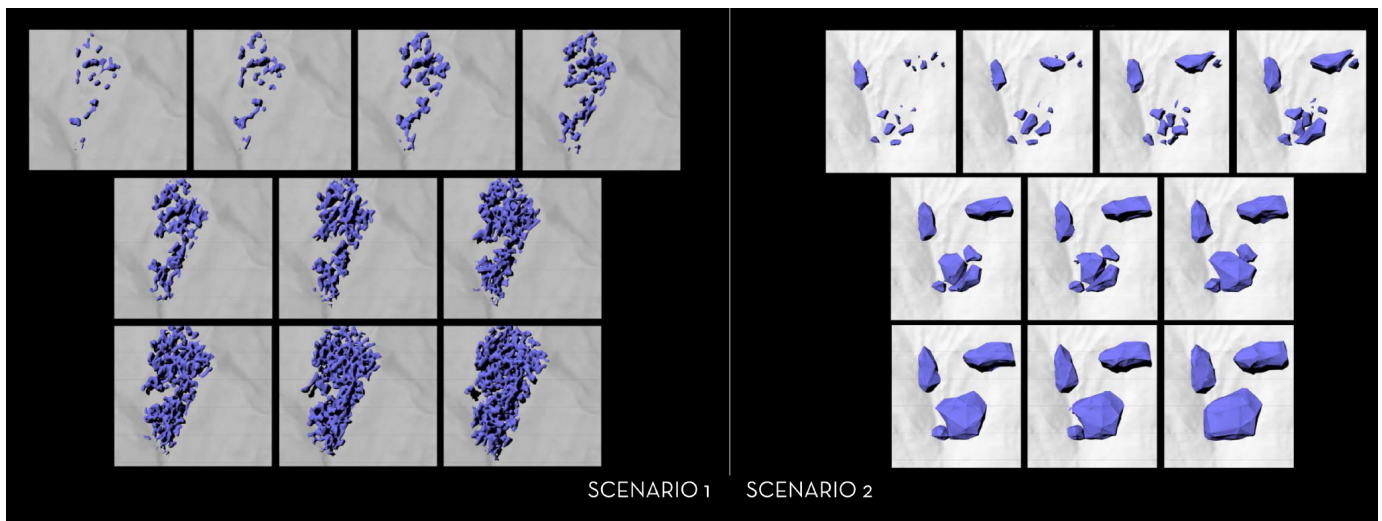


Figure 5d. First growth studies. Comparison of scenarios with opposing characteristics

The determination of starting points for settlements: two opposing scenarios

Even though, our hands-off approach to design aims to establish self-organizing systems they must be initiated. To this end, two independent and opposing scenarios were run through and their processes and effects compared, as the people usually strive for the seemingly most favourable site for the construction of objects, infrastructure or settlements within given boundary conditions. In order to combine the parameters individually described above, the effect of the terrain, the exposure as well as the long-term effect of these influences were used to evaluate and select the starting points for the settlements.

Thus, for a first scenario, the supposedly most favourable areas of the terrain were filtered out in order to have as little impact on nature and the landscape as possible. The sunniest spots in the terrain were chosen, the analysis of the fall lines of the water flow was used, so that later objects would not be placed directly in the fall lines and negatively influence the water flow. Round shapes are preferred according to the above analysis in order to amplify wind flows as little as possible and also to keep wind pressure and wind suction on the objects and the terrain low (Figure 6a).

In an opposite scenario, the setup was designed to influence nature and landscape as much as possible. In other words, we established the opposite of the above scenario. The shadiest areas of the terrain were selected, where the least sunlight is expected. The settlements' starting points were placed in the middle of the fall lines, so that the natural flow of water is interrupted and redirected by the objects. Thus, the water must constantly seek new paths. The shapes in this scenario were chosen to be angular to allow as much turbulences as possible to be created by the wind. Wind pressure and wind suction also increase steadily in this way.

Ultimately, whether initiated in a favourable or in an unfavorable area, does make much less of a difference as the comparison of figures 6a and 6b suggests, because the scenarios are basically parts of the same cycle and as described below primarily a matter of time.

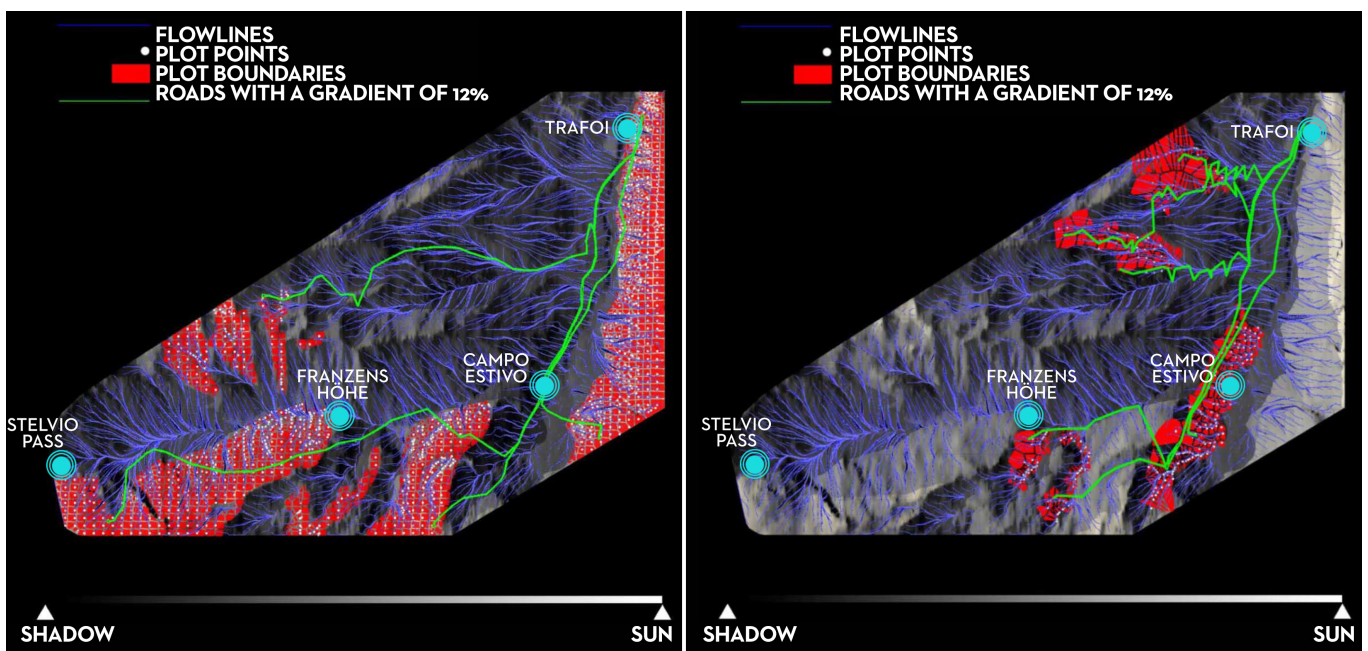


Figure 6. First growth Studies. Comparison of Scenario one and Scenario two.

The cycles of scenarios as a matter of time

Even if the settlement is "founded" in an advantageous area of the terrain, the system does not remain static but is subject to the natural influences of wind, water, sun, etc. The landscape changes due to both natural conditions and man's intervention through his artificial objects. Thus, the incipient process reshapes nature as well as the settlements themselves. In our study, therefore, we do not make a distinction in this regard, but subject all components to the same hands-off approach, without trying to direct it in any particular direction. It is also clear that these are long-term and slow processes, so we are talking about time spans up to nearly 600 years.

For example, due to the formation of grooves, more and more shade falls on the supposedly advantageous terrain, the settlement is forced to shrink and relocate not least because of the changing water flow. Eventually, the site becomes an unfavourable one. However, after a certain period of time, this scenario changes due to the same parameters and the modified settlement structure itself and the accompanying compaction of the soil, which slowly makes the site an advantageous one again. Thus, a natural cycle of a settlement is created, which in principle is constantly repeated, a cycle in which the advantageous site becomes an unfavourable one and later becomes an advantageous one again (Figure 8) without, however, ever repeating an identical formal expression.

In a study starting from the supposedly advantageous terrain, transforming into an unfavourable one and returning to be advantageous the full cycle covered a time span of 570 years (Figures 7a-f). Our steps of iteration were corresponding to 30 years for reasons of computing power and time, but mainly to make the changes visible. The maximum wind speed in this study was set to 15 m/s with a representative wind direction from southeast. Depending on the ratio of sun and shade the shapes of the settlement transform to more angular (Figure 7b) or more curved. However, the wind streams are not yet swirling as much because the structure is still small and at a favourable angle to the wind.

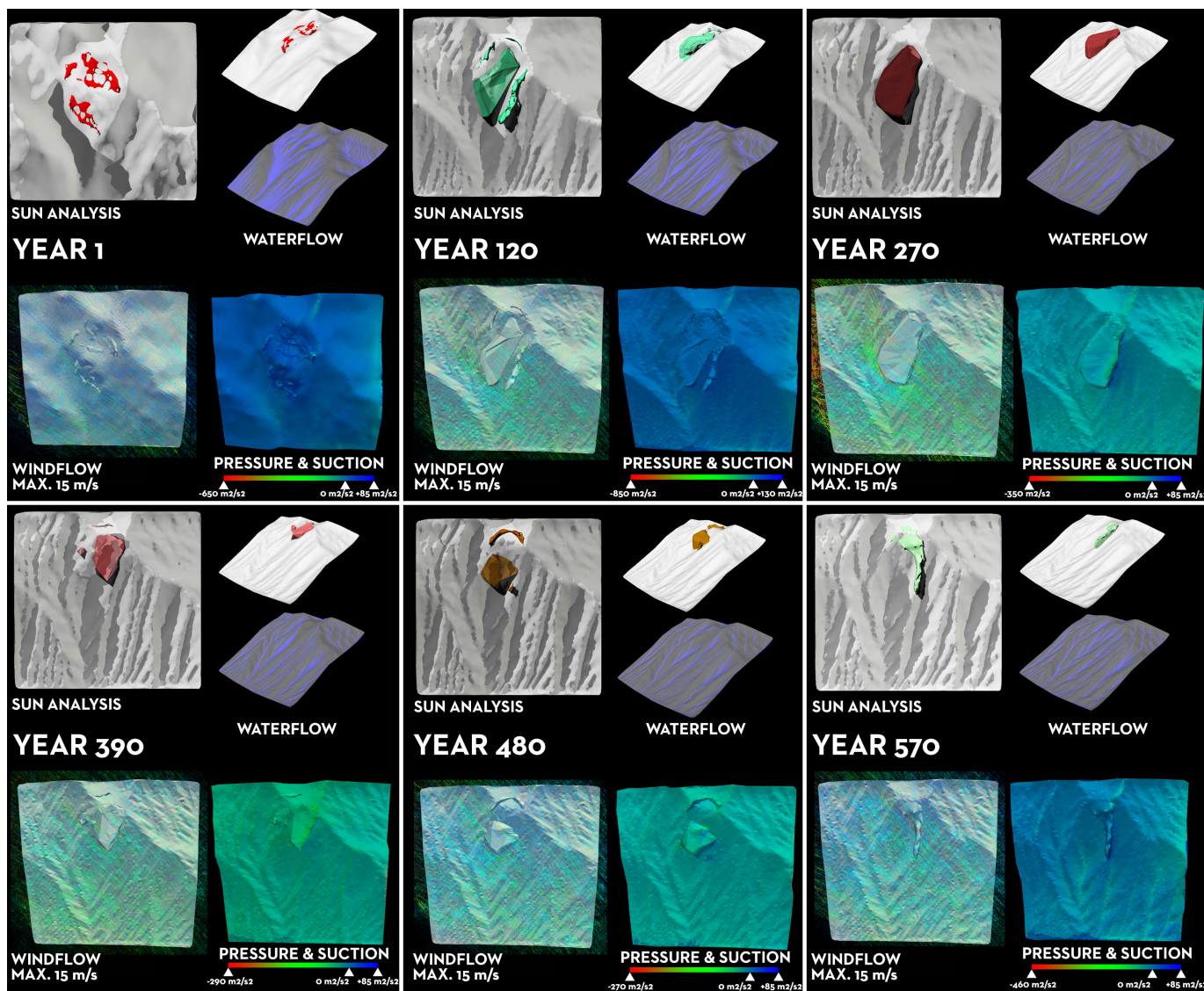


Figure 7a/b/c and 7d/e/f. Settlement Evolution. Sun , Water Flow, Wind Flow, Pressure and Suction Analyses of the Settlement and the visible changes in Year 1, Year 120, Year 270, Year 390, Year 480 and Year 570.

As the shading increases, angular shapes become more dominant. Consequently, the flow of water is influenced, redirected and increased, and therefore increasingly changing the terrain. This in turn leads to a new ratio of light and shadow. In this case study, after 90 years, the fall lines of the water are strongly deflected by the angular shapes, but less so by the round shapes. The round shapes now are situated between the fall lines and do not affect the flow of the water. Altogether, the setting shows its effects even on redirected and deflected wind streams. After 270 years (Figure 7c), all structures have transformed into angular shapes, which on the other hand represents the turning point in the transformation process. Figure 7d shows a new advantageous settlement emerging on the site. The dominant angular shapes seal the ground and prevent it from erosion so that a favourable location can be created here again. In this specific simulation, after 570 years (Figure 7f), the unfavourable structure has completely turned into an advantageous one (Figures 7a-f).

As above mentioned, the terrain is considered advantageous from the perspective of the sun-shade-ratio. However, in terms of wind especially from

southeast the site is quite exposed, in the early years of the cycle. After the cycle of 570 years, however, the wind is much calmer, as the area is protected from this direction by the newly formed terrain in front of the settlement.

The seed of a settlement placed in the valley

In an extended study, the entire area of the Stelvio is subject to settlement growth, considering only advantageous spots in the terrain. Here, the starting point of growth is located in the valley. A starting point can be understood like a seed from which the structures begin to grow. Similar to plant growth the settlements grow across the terrain, following sunlight, water, fertile soil and preferable in vertical direction. The initial seed is placed where the main streams of the water flow cross.

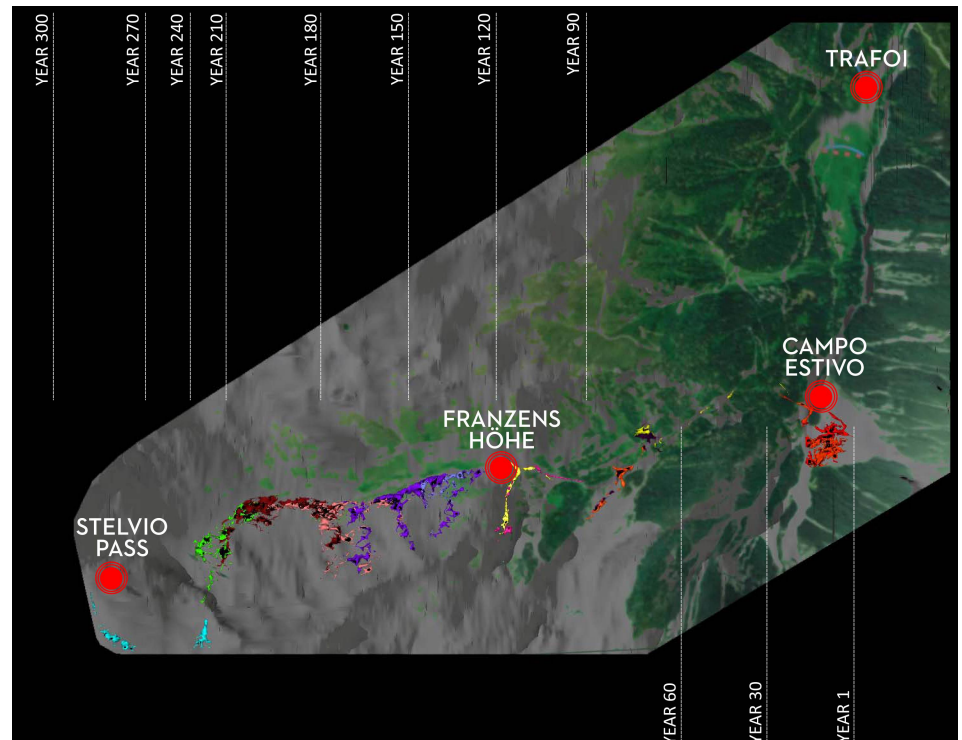


Figure 8. Starting from the Valley. Entire Settlement growth from the valley to the mountain over a time span of 300 years.

Figure 8 shows the development in steps of 30 years, which are also indicated in different colours. The settlement structures are self-organized in their growth as they oriented themselves according to the main water flows and the preferred sunny areas. The settlements are considerate of their surroundings, such as trees and green zones, the constantly changing terrain both topographically and due to erosion, while only a very narrow sunny ridge leads upwards, and which is why this place is sparsely populated. The settlement uses its environmental conditions to grow by consuming the climatic conditions from the area at its best, but without destroying it. Surprisingly, the water flow is little influenced by the structures of the settlements. Once the settlements have crossed the tree line, they spread over a larger area as they wind their way up through it. The structures are always densest near the main stream of the water. The side slopes are more sparsely populated as shaded areas continue to encroach on the landscape here. As indicated in Figure 8 the speed of growth is quite diverse and finally, after 300 years, it has reached the top of the Stelvio pass, where the present settlement is located.

The seed of a settlement placed on the mountain

In an opposing study, the seed or starting point of settlement was placed at the top of the Stelvio pass, the location of the current settlement. The process is basically the same as in the previous study, but some differences with significant implications can be notified. First, since there is more solar radiation in this part of the terrain, initially the settlement grows much faster. However, the self-found path toward the valley is similar to the previous study, when the settlement grew upward from the valley. Again, the structures establish themselves at a safe distance from the main waterfall lines, close enough to benefit from them but far enough away to have little influence on their course. Nevertheless, it is noticeable that the self-organized growth of the settlements in the upper third of the Stelvio is much less pronounced than in the previous study. On the other hand, in the area of the tree line, there are settlement structures that were not established or were much less pronounced in the previous study. Obviously, the effects of the higher settlements have caused shaded and sunny areas to develop differently.

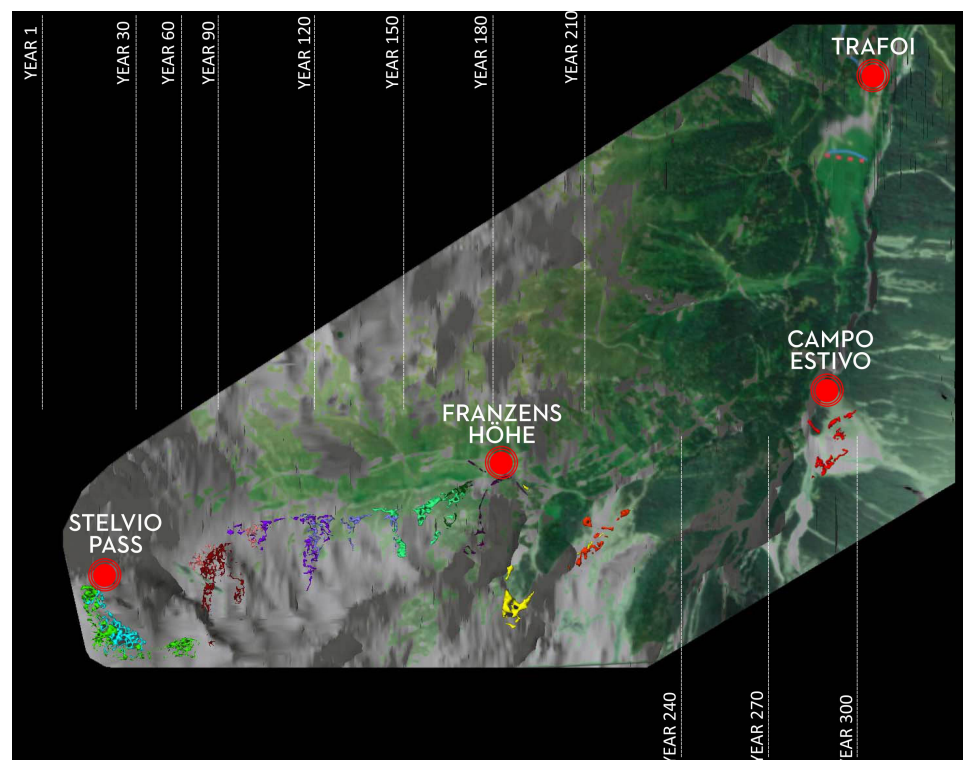


Figure 9. Starting from the mountain. Entire settlement growth from the mountain to the valley over a time span of 300 years.

The decisive difference occurs after about 270 years. Here the settlement has reached the end of its growth, because it had blocked the way down by its own shading and erosion process. Following the concept of maintaining an unfavourable structure in order to create new favourable places for the future (Figure 9), the simulation period would have to be extended significantly, a study, which was not performed yet.

Existing settlements as seeds

Along the route from the valley to the top of the pass, there are several settlements that are considered in this study as starting points for new settlement growth. Some of these existing settlements are larger, such as the village of Trafoi in the valley with about 80 inhabitants (Gemeinde Stilfs 2016), or the settlement at the pass itself. Others are small, such as the Franzenshöhe Hotel

or Campo Estivo in the valley, which is an abandoned police barracks. According to the size of the settlements, for this study the growth was weighted, the two larger settlements with stronger growth, the two smaller ones with lower growth. So, the growth of these settlements happens in all directions (Figures 10a-c). Simultaneously a system of decay has been superimposed on the process. What can be noticed, however, is that the structures grow faster, while their decay is much slower. That is why the area becomes populated very quickly, very densely. Nature, on the other hand, reclaims its habitat much more slowly.

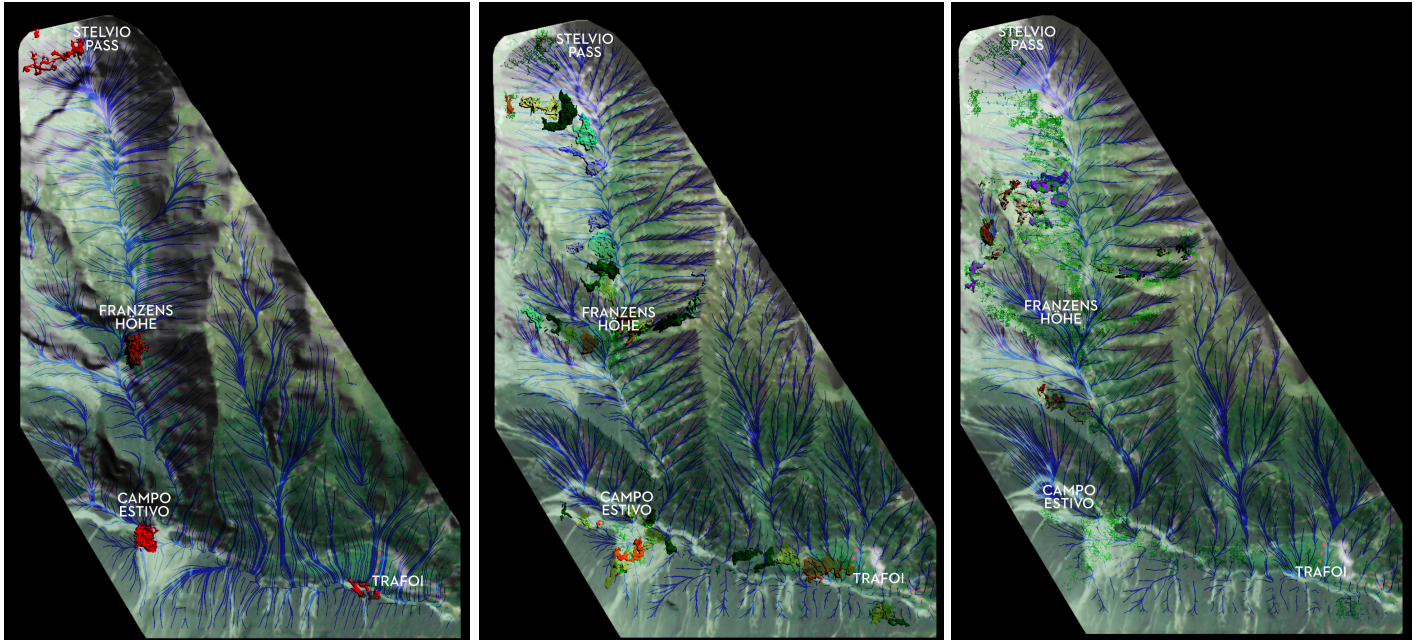


Figure 10a/b/c. Different Starting Points. Settlement growth from various starting points in Year 1, Year 150 and Year 300.

Only after 120 years, the first grown settlements have almost disappeared. Where parts of the settlement structures have already disappeared, growth would basically be possible again. In this study, these areas are excluded from being reoccupied and will not be resettled. Especially in the valley areas, some settlements will have reached the end of their growth because of spatial limitations. Due to similar reasons as explained in the previous study where the seed of a settlement was placed on the mountain, the four settlements of Trafoi, the Campo Estivo, the Franzenshöhe and the Stelvio develop and stay separately. After 300 years, the growth process in this study has come to a halt, as further growth can occur in the areas of decayed settlements only.

From the macro to the micro scale

In order to define the settlement structures more precisely, a small part of a settlement is singled out to analyse it again with the same parameters. As shown in figure 11, a shift from the macro scale of the terrain, to the comparably micro scale of the still abstract structures themselves.

A sunlight hour analysis (Figure 11) is performed for the surfaces of the settlement structure and plant growth across the structures and settlement is applied accordingly. In parallel, a water flow analysis (Figure 11) on the surfaces, on which the plants then nestle up, is needed for learning about the distribution and accumulation of water in dependence of the surface curvature and exposure. As a consequence, locations with increased nutrients for the plants could be determined. An overgrowth analysis shows which parts and how dense the

settlement structure is overgrown by plants. These plants are at the same time partly responsible for the decay of the structures, among many other factors. Furthermore, this plant overgrowth means a kind of second materiality for the settlements. This materiality, like the entire process, is thus dynamic. For example, the leaves of the plants protect the structures from strong sunlight in summer, while in winter they in turn allow more sunlight into the interior of the settlements. Plant growth was assumed cyclical in our study, and by combining the parameters it is possible to observe from where the plants grow over the buildings, where they grow to, and which areas are the most overgrown. This again corresponds to a self-organizing process, which at the moment is considered in retrospective and does not have a shape generating function in this investigation.

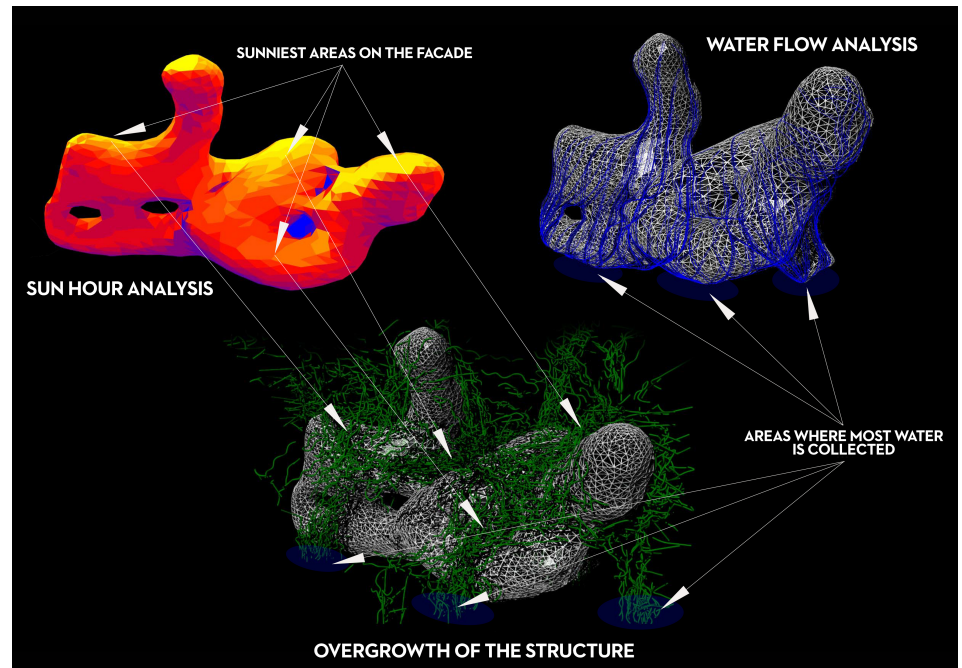


Figure 11. Parameters on the Structure. Combination of the sunlight-hour analysis, water flow analysis and overgrowth analysis on a structure emerged from a self-organizing process.

An outlook on speculative organizational patterns, structures and settlements

Based on our research and case studies, as well as the selforganizing processes of shape formation, we have engaged in a speculative design process with structures of nature, from flora and fauna, as well as new fabrication methods and innovative biomaterials, in order to integrate the growth and decay of structures in an architectural scale into the overall concept and to overcome the abstract thought model and simulations. Although different material compositions and structures were discussed and explored in preliminary design studies we show only one of many examples as a comprehensive research-by-design exploration is beyond the scope of this paper. The following specific study, we looked into examples of insect wings, certain types of lichen, or even eroded rocks after which the structure of the settlements have been modelled by the use of the Dendro software application. The suggested materials include printed clay for the load-bearing structure and transparent wood (Mi et al. 2020) for the transparent parts of the skin. The structures are supposed to be printed with the MUPPette aerial 3D printer drone (Mortice 2015), which will allow the entire building to be printed in one operation, thanks to the combination of the MUPPette

drone and a multi-nozzle print head (Overvelde 2019). Such technologies allow buildings organically, similar to trees (Mortice 2015). To emphasize the multi-materiality of the structures, they are assumed being made of very rough clay on the outside, which is created by the layers of 3D printing. Thus, there is a possibility that plants and mushrooms will adhere to it, and due to the high content of weather able minerals that make up clay, it forms a good storage capacity for nutrients and water. Therefore, clay provides a good substrate for fertile soils (Volhard and Röhlen 1999). Clay also stores heat, it regulates humidity in the environment, and the moisture of adjacent materials (Röhlen and Ziegert 2020). The plants that cover the buildings filter pollutants such as dust out of the air (Weber et al. 2014). This process intensifies over time as the buildings become overgrown with plants. The structures then begin to function as filters for the air. Erosion brings debris and stones that are deposited on the facades, especially where the water passes the facade. These stones can also be understood as another dynamic material, similar to the plants that grow over the structures. Further, the shapes of the buildings are reminiscent of tree resin, which adapts to the unevenness of the ground, like a natural glue or roots. Even grafting techniques from plants (Wiechula 1926), which can be considered as a second dynamic materiality for the structures, resemble the pattern of the settlements (Figure 12).

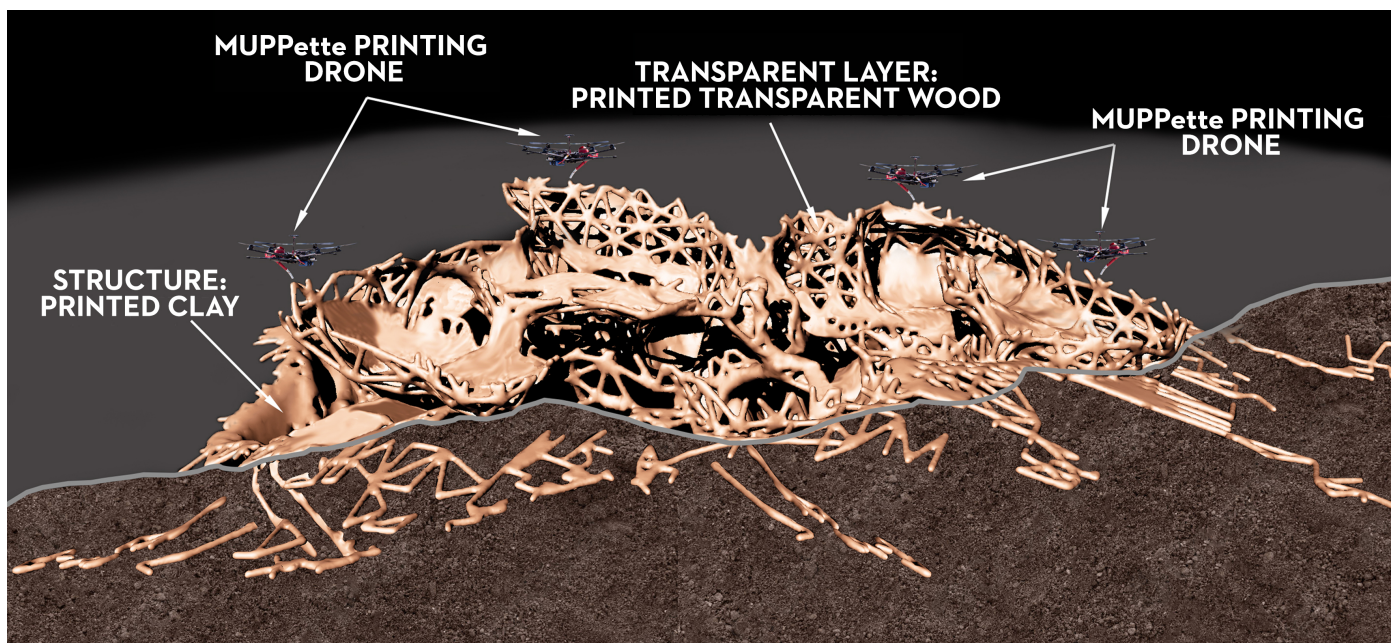


Figure 12. The settlement structure. Section through a settlement structure with the proposed materials and the MUPPette 3D printing drone.

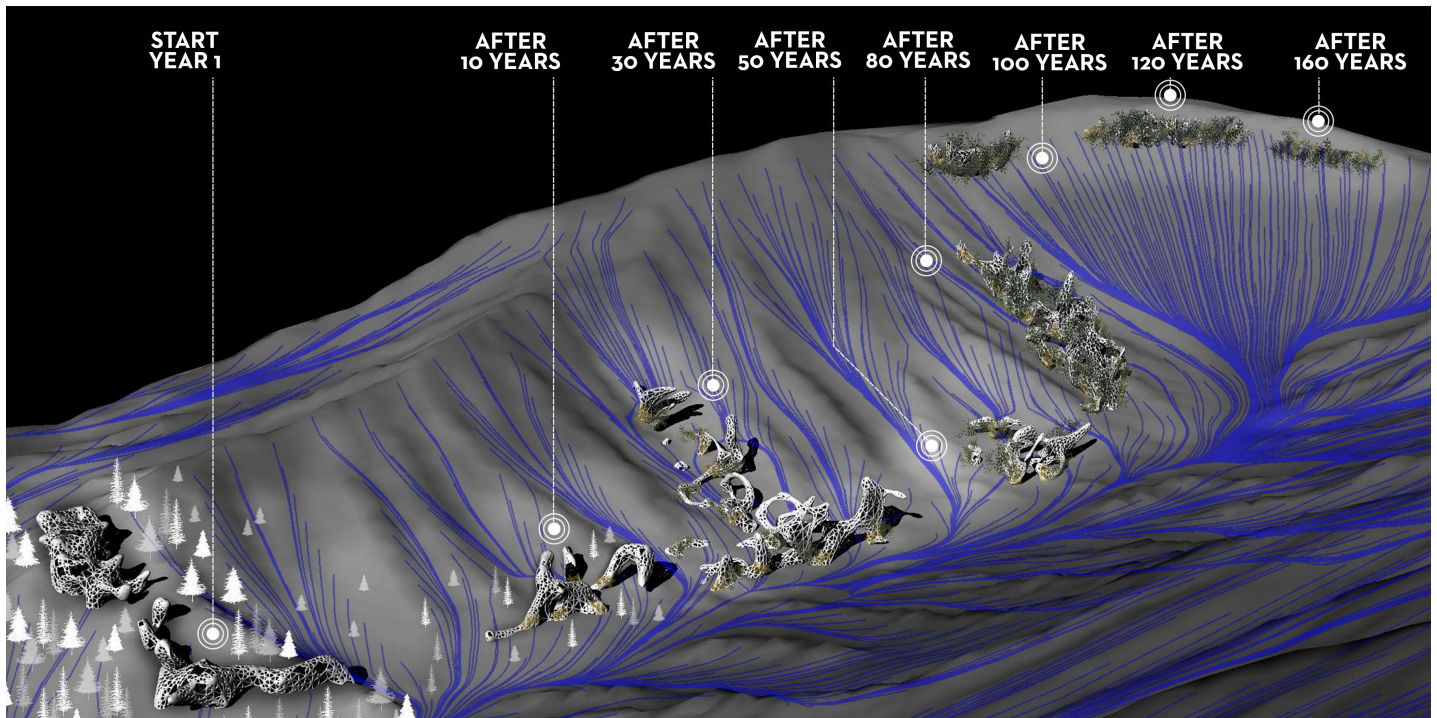


Figure 13. Settlement Erosion. Different stages of the decay of the settlements over a time span of 160 years.

Since the entire footprint of a building should be included, and not just isolated individual performances, but the variety of requirements for buildings (Stalder 2021) the decay of the settlements and their components is equally important to their growth. Wood and clay are materials of natural origin and therefore do not need to be industrially produced. Therefore, once the buildings decay, they do not pollute the environment, but simply return to their origin. Similar to erosion processes, buildings are also simulated and assumed to erode or decay in a very long process that depends on known material properties but is also speculative to a certain extent. Overgrowth of plants is one of these factors. So, the decay of the buildings forms another cycle and in our simulations is completed after about 160 years, whereas the settlements themselves are habitable for about 50 to 60 years only before they are completely abandoned to nature (Figure 14) as fertile ground. Thus, there is no need to demolish the structures or to maintain them.

Decay also contributes to the alternation of sunny and shaded areas, to the associated erosion processes, in terms of wind flow and so on. The cyclical processes explained and simulated for the macro scale is repeated in meso and micro scale. In this regard, it would be possible to zoom infinitely into the matter (Figures 14a-d).

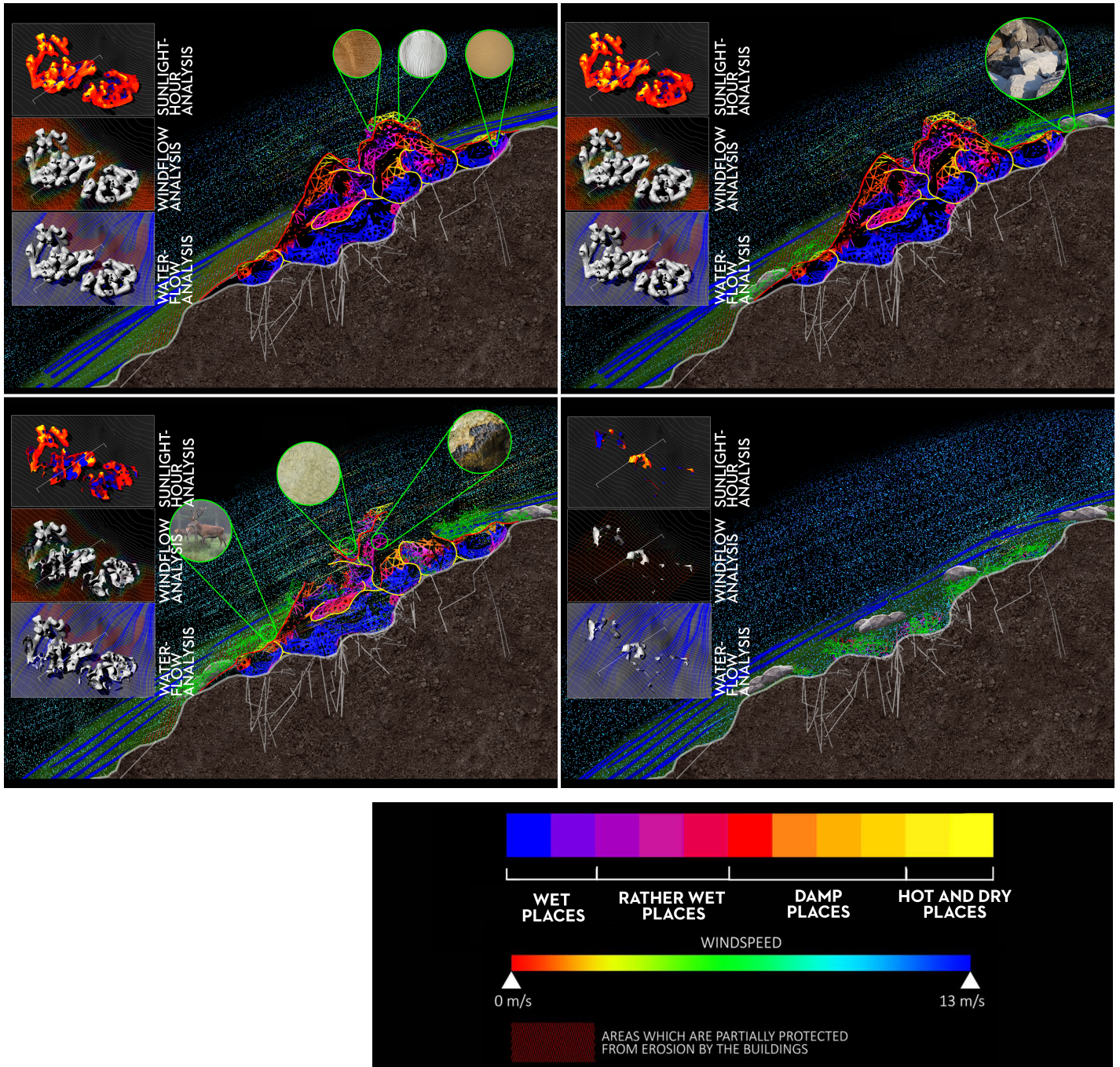


Figure 14a/b and 14c/d. Cycle of Advantages and Disadvantages. Section of a settlement structure with the overlay of the different parameters and how they are changing over time in Year 1, Year 30, Year 80 and Year 160.

Conclusion

The objective of our research was to explore self-organizing systems for and in architecture, with an emphasis on growth and decay. So, the unusual aspect of our approach to architectural design and settlements is to reconsider self-organizing phenomena to initiate and describe the formation, growth, change processes and decay of settlements. Clearly, the set of parameters that were considered are most basic and can be further complemented. For this reason,

we are describing but not evaluating the outcomes of two opposing scenarios and the matter of time, since our simulations cover timeframes of up to several hundred years. We are also not proposing or setting up rules, but we show principles that can serve a better understanding of the proposed approach. The shown forms are a result of the interaction of parameters and time to be understood as complex diagrams of self-organizing processes. Thus, resilient organizational patterns of settlements with architectural qualities can be recognized. The Stelvio region, a "vertical landscape" in the Alps, with its extreme conditions, a simultaneously natural and human-shaped landscape served as a test field for our investigations for several reasons. These include the high diversity in climatic nature, the differences in altitude, various slopes in the terrain, humidity, but also the different vegetation (Carro and Pedrotti 2011). At the same time we had excellent access to input data such as topographical information, weather data and personal access to the landscape for site visits. In order to create a self-organizing system we defined several parameters, which are superficially physical laws. These parameters were first studied individually, to better understand their impact on the landscape, different parts of the site, but also on objects before they were linked together. These parameters include a solar-analysis, erosion (SWAP | AADRL 2012) from the water flow (Ryan 2012), wind (Ibrahim 2020), pressure and suction on objects, growth and decay. These parameters are used to explore and visualize their mostly nonlinear processes and effects on the natural, but also on the built environment as a means of design methodology.

The results of our initially separate simulation show processes of transformation that constantly adapt to landscape topography, to climatic conditions and under the associate physical laws. Stepwise our simulations are overlaid, merged, tested, observed and evaluated on the representative test fields. The observations include changes, cycles, the growth but also the decay of natural and inhabitable structures. Our simulations show that by choosing different locations, it would be practically possible to influence terrain changes, e.g. by diverting water flows. By implementing settlements or buildings, new hills, new valleys and even lakes are created in an indirect design process. This could contribute to the protection of landscape, flora and fauna in the future. These processes do not happen overnight; it takes several hundred years to reshape landscapes damaged by climate change. However, it seems possible that architectural interventions may be able to transform landscapes, possibly regenerating them and create new, better conditions. As described in the introduction, self-organizing systems emerge as a result of the conditions set - usually natural ones. However, these principles can also be applied to architecture, but require a paradigm shift in thinking away from the architect as a designer of forms to a master of constraints.

Altogether, our investigations suggest a novel hands-off approach to design, to create settlements as self-organizing systems of growth and decay that is exemplified in a speculative settlement structure design experiment. Even though, our approach has been applied to a specific site and case study with the potential of being modified for other locations on our planet, we are aiming for conceptual design thinking strategy (Deo et al. 2020; Filz et al. 2021) rather than a directly realizable planning procedure. An interesting finding that our simulations have brought to light is that over large periods of time it makes no difference whether one chooses supposedly "favorable sites" or "unfavorable sites" for one's interventions, since these change constantly over time and are ultimately snapshots of cycles.

However, our studies suggest concepts for informal (OECD Statistics 2021), unthought forms (Mario Andres Ojeda Casanova 2018) and structures of settlements that cyclically reshape and reorganize in, through and with the landscape in an environmentally compatible way by passively and actively

influencing erosion, redirecting water and purifying airflows, but also integrate and adapt to the natural environment, equally including humans, animals and plants.

Future implications

The behavior of self-organizing systems in this study was limited to a single test site, Stelvio. Further research will examine the system at several different test sites, as such systems could be applied to any location on our planet. It is possible that other, new parameters will have to be defined there. The selection and extension of relevant parameters into a complex system is another future challenge in this context. Adapted to the conditions of other locations, such new parameters will most likely lead to modified formal results, but will follow the same principles. Another interesting approach will be to complement the settlement patterns with parameters related to productivity, i.e., energy production, water harvesting, etc. Self-sustaining, adaptive building (Markou et al. 2021; Sanchez-del-Valle 2005; Sobek and Teuffel 2001) and settlement typologies could thus be explored. Our design approach also requires the development of materials and technologies from a variety of fields, including the development and use of biocompatible materials, as well as new approaches to assessing the lifespan of habitable structures. Although the study shown in this paper is only one of many investigations and one of an infinite number of possible configurations, the discourse on materiality and technology available today seems highly relevant to the authors, and different material compositions and structures were discussed and explored. However, the application of the principles presented in a comprehensive and representative research-by-design study is an urgent future task of great relevance and only touched in a very speculative manner so far. But, the study shown highlights the potentials of our proposal, and yet it reveals the shortcomings of the materials and technologies we use today, which lag far behind simulations in terms of feasibility, sustainability, and flexibility.

The inclusion of growth and decay is in conflict with our society's idea of standardization and norms as such approaches might be a subject of safety discussions. However, growth and decay as an important aspect of sustainability may also influence our perception of future architectural aesthetics.

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