

MANAGING UNCERTAINTIES IN URBAN DEVELOPMENT AND CLIMATE CHANGE ADAPTATION: A CASE STUDY IN ADAPTATION IN A COMPLEX COASTAL ENVIRONMENT USING DYNAMIC ADAPTIVE PATHWAYS IN SKIVE, DENMARK

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The city of Skive, located in West Jutland Denmark, is looking to develop a long term strategic urban development plan integrated with supporting climate adaptation pathways keeping Skive climate-proof for future conditions. In this study a Dynamic Adaptive Pathway Plan (DAPP) was used to investigate uncertainties with regards to future climate change and urban development. Similarly to uncertainties regarding climate change (e.g. Sea-level rise) and the associated change in risk, there is great uncertainty in the future development of the system (Skive) through a range of socio-economic variables. This will directly affect the solution space for climate adaptation. NIRAS, LYTT Architecture and Skive Municipality have developed a strategic urban development plan and investigated the implications and possibilities for climate change adaptation in Skive. It is one of the first fully developed DAPP processes in Denmark. The project illustrated the need for supporting uptake of dynamic decision making, the necessity of multi-disciplinary collaboration within the municipality, and the integration of land use considerations within the adaptation pathway development.

Keywords: Climate Adaptation; Dynamic Adaptation Pathway Planning(DAPP) ; Sea-level Rise

INTRODUCTION

Background

The city of Skive is located in the West of Jutland, Denmark. Skive has a history of being a town close to the water. In the future the lowest parts of Skive are increasingly at risk of flooding from the nearby Fjord, several streams, rainfall and shallow groundwater, making Skive susceptible to climate change.

Skive is looking to develop a long term strategic urban development plan integrated with supporting climate adaptation pathways keeping Skive climate-proof for future conditions. NIRAS and LYTT Architecture will develop, together with Skive Municipality, a strategic urban development plan and investigate the implications and possibilities for climate change adaptation in Skive. The study area is shown in Figure 1, where the black dotted line illustrates the study area perimeter. It features a mix of urban area, a shopping mall, a stadium, commercial industry, various low housing areas, sewage treatment plant, industrial harbour, fishermen huts, drained grass fields, both a channeled stream, main roads, delta, protected bog and meadow as well as a NATURA 2000 protected river.



Figure 1. Study Area of Skive (LYTT Architecture, 2022)

The challenge in this study is to integrate the uncertainties with regards to future climate change and urban development. Similarly to uncertainties regarding climate change (e.g. Sea-level rise) and the associated change in risk, there is great uncertainty in the future development of the system (Skive) through a range of socio-economic variables. This will directly affect the solution space for climate

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adaptation. This present study seeks to approach these dependencies by implementing a portfolio-based Dynamic Adaptive Pathway Planning (DAPP) process facilitating strategic urban development by integrating climate change adaptation.

Physical Conditions Skive

Skive is exposed to a number of climate stressors and impacts, primarily inundation as a result of storm surge levels in the Fjord and as a result of rainfall events. Both stressors also cause inland flooding as there are two rivers extending through the project area. For this study, rainfall is included however the primary driver is the increased risk of flooding resulting from inundation from the Fjord, as the dimensions of sea level rise is considerably larger than the expected increase in precipitation and cloud bursts.

Skive has developed from the brink of the river Skive Å, that runs out through the project area. The city has been partially built on the sandy low-lying flood plains and from north another stream runs through the project area. Flooding caused from heavy rainfalls and river discharges coming from upstream in other municipalities therefore greatly affects the risk of flooding in Skive. In the low-lying areas groundwater is already being pumped into the river, and this activity will see a significant increase in the future if decided to keep these areas dry. There is a moraine deposit near the Fjord that increase the response time of groundwater level when storm surges occurs, reducing risk of seepage during storm surges.

As can be seen in Figure 2, the flood risk increases as a result of projected sea-level rise. Note that in this case a static inundation model is used, where the inundation depth is adjusted to represent future flooding scenarios. As a result of using a static inundation model, it overestimates the inundation extent as it cannot account for protective measures that are present at the project site. It does give a good understanding of the residual risk, and considering future conditions once the crest height of the current protective infrastructure is exceeded during an event, which will occur with increasing frequency.

Currently the protective infrastructure has a crest height of +2,5m, meaning that a present day annual exceedance probability (AEP) of 1% will not exceed the current crest height of the defenses (Figure 2). What can be seen however, is that the residual risk is quite large on some of the places along Skive Å. Looking on the right side of Figure 2, it can be seen that a future 1% AEP exceeds the current crest height and adaptation is required to prevent flooding. Further, the inundation depth is increased considerably in most of the project area.

The 1% AEP in Figure 2 is the future scenario of a 8.5M RCP where, depending on how emissions track in the coming century this condition will either move forward or backward in time. It is therefore important to consider a range of future scenarios. In order to face this deep uncertainty brought on by climate change, we are using a dynamic adaptation method that is able to account for future changes in risk as a result of climate change.

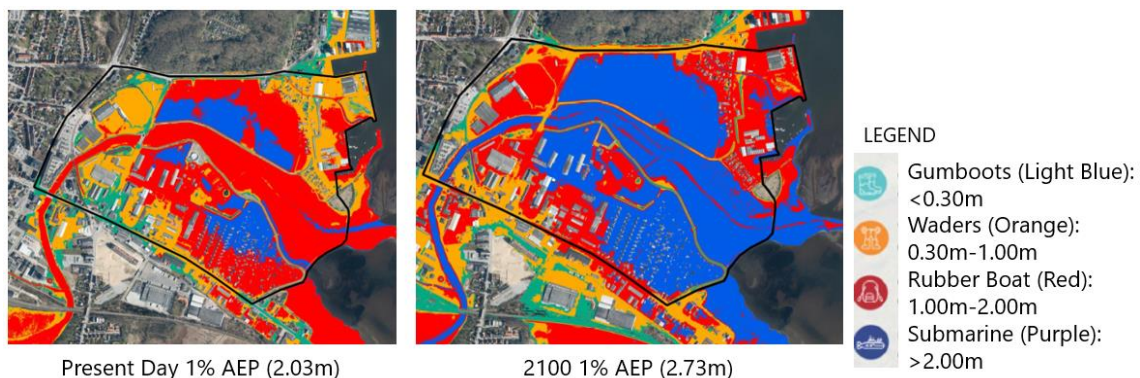


Figure 2. Inundation extent Skive using a static inundation model The future scenario shown is based on RCP 8.5M

- An extensive workshop of knowledge transfer from Skive Municipality to NIRAS as well as an alignment of expectations, success criteria and failure conditions for both city development and climate adaptation.
- A thorough desk top study of the system and outer forcings of both land use, social, economic and urban development and status. This also included existing natural systems (all types of water, habitats, sewage systems, existing climate adaptation measures etc). Urban plans, regulations and future visions were also included.

Based on this, a list of possible adaptation measures fit for this area (geographically and economically) was listed and individually scrutinized with regards to, cost, effectiveness, effect on multiple issues, risk reduction, need of maintenance and emergency preparedness, natural and aesthetic qualities, implementation time, and adaptive potential.

The list of adaptation measures was then evaluated in relation to each other in a general DAPP map for each type of problem it was to address. This informs which measures are preferred for which areas and at what time in the future, as well as some are discarded as they do not facilitate a desired urban development. Based on discussions concerning success, failure conditions, visions, realities, synergies and conflicting interests the DAPP diagrams were set up for sub-areas combining the various issues they are to handle. A multi criteria analysis was set up evaluating the adaptation measures in the light of new knowledge. Based on the above 1-4 urban development scenarios was set up for each sub-area based on the possible climate adaptation pathways for the corresponding area.

Development Uncertainties

Just as it is difficult to plan in the face of climate change uncertainty, the system (Skive) can also not be treated as a constant. This is because over time, the city will develop bringing changes both in terms of exposure and vulnerability contributing to change in the overall risk. As can be seen in Figure 3, over the last century Skive has developed around the Skive Å, gradually developing around the floodplains and increased densification of the settlement near the Limfjord.

This means that regardless of future climate change uncertainty, the development in the town will have its own contribution to the overall risk and residual risk. They also have an inherit uncertainty associated with them, as depending on development choices it will either constrain or enable for adaptation to be implemented.

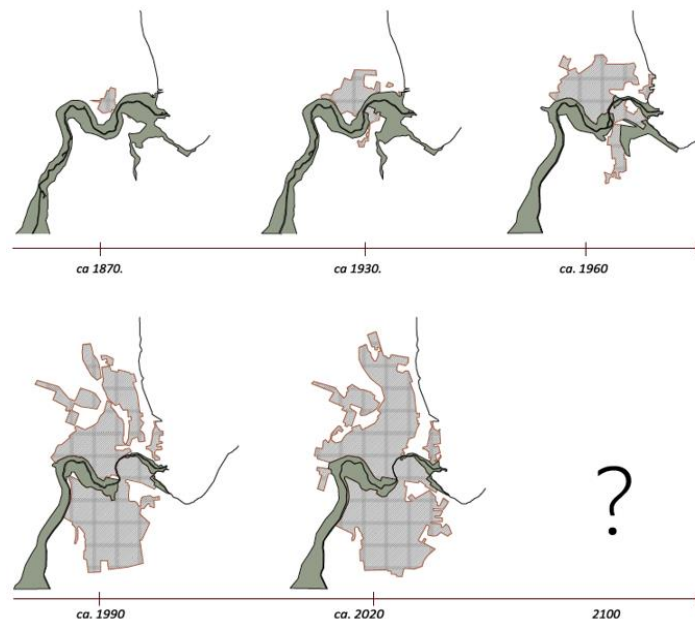


Figure 3. Inundation extent Skive using a static inundation model (LYTT Architecture, 2022)

Also (environmental) regulations have impact on the solution space. In Denmark new regulations for rinsing of water led into rivers and seas have resulted in new criteria. Municipalities have to find areas for the creation of new stormwater ponds, This means Skive must reserve space in their planning for areas to be permanently flooded.

When developing these adaptation pathways in response to changes in climate stressors, these development changes also need to be taken into account and aligned with the adaptation planning. Short term development choices can potentially constrain adaptation in the long term.

In order to integrate these two concepts, we will disaggregate the study area into different subareas where future development visions for each of the subareas are developed in stakeholder workshops. Along these considerations pathways will be developed that can support these developments. This is an important process, since some adaptation pathways can exclude the possibility of a certain development, just as certain development choices (both short and long term) can be an enabler for the implementation of certain adaptation choices.

Stakeholder and co-production process

Throughout the DAPP process a number of participatory processes have been held in order to explore future development visions for Skive, as well as the integration with adaptation planning. The following participatory processes have been set up aiming at various groups and interests:

- Big Blue Forum: Local Stakeholders and politicians (business owner etc.) – enclosed workshops
- Open Community Involvement at library (various adult groups) and poster installation
- Green Innovation Week (Universities) (young adults/teenagers as well as politicians)

The Big Blue Forum was a committee on which the project findings and ideas were tested several times through presentations and workshops. The project is dependent on their approval, as they are key to setting the adaption measures in motion, and as they are the ones to drive the city development.

The Open Community Involvement at library aimed was primarily a presentation of the project frames, climatic drivers and visions for the city as well as an open discussion of what the citizens felt and thought about this and wished for. Posters were exhibited on the library for a couple of weeks during summer holiday time afterwards, with a mail box as a feedback channel from the viewers.

During Green Innovation Week, young adults and teenagers as well as politicians were invited to an open workshop. The participants was provided with current development ideas and extent of the project area, but also with drawings from future fjord water levels changing the conditions for development. This is shown in Figure 4, where the rise in water level in the Limfjord (Both mean and extremes) will start to squeeze the current protective line and developed infrastructure This visually illustrates how the conditions will change over time, constraining the amount of space for development and natural habitats. In other words, it shows that the current situation is not stationary, and will have to be adapted over time as it will look quite different in the future.

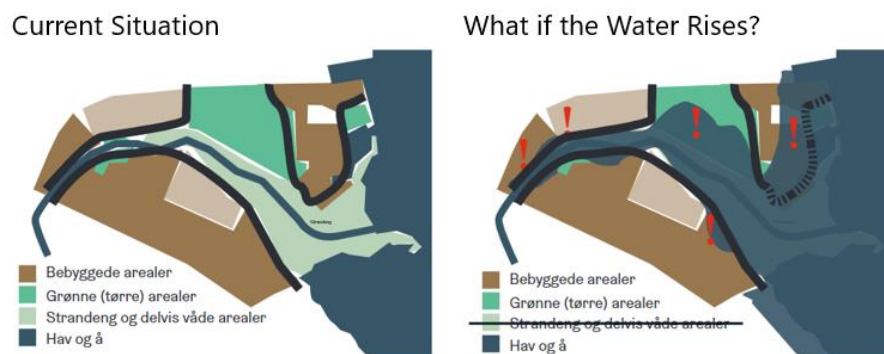


Figure 4. Figures used during the workshop to illustrate future non-stationarity (LYTT Architecture, 2022)

Feedback from the involvement process was discussed and evaluated and used as guidance for the city development and climate adaptation scenarios. Furthermore it was used as part of the foundation of multicriteria analysis criteria.

RESULTS

The DAPP process has been implemented throughout 2022 and will be completely finished in the first quarter of 2023. The Municipality have become aware of risks from various types of water and the 'do-nothing-baseline scenario' as well as potentials and constraints in the area. The process has been enlightening and enabled the Municipality to make decisions both about subjects to act on now and subjects to wait with acting on.

Based on the workshops, the socio-economic analysis and desktop study evaluating outer forcings on the system, the Skive area has been divided into different sub-areas. When the initial adaptation pathway maps were developed for the subareas and discussed with future development the Municipality realized various unacceptable developments because of long term climate change uncertainty, such as new development in especially vulnerable areas. Similarly, they identified obvious choices for their city and corresponding climate adaptation.

For each of the areas, a unique adaptation portfolio was developed with associated development possibilities for the subarea. The scenarios therefore reflect, that the Municipality is already anticipating the initial pathway change, which does not need an immediate decision, but in order to make a future decision requires engagement and additional consideration of associated tradeoffs.

The project was finalized developing both a report on all of the above steps as well as an action plan listing the overall measures to be done within the next 100 years in order for facilitating the visions of the city development (and environmental growth). This while reducing the risk of flooding or ruining precious nature.

The results of the project will be outlined in the following paragraphs.

Stakeholder Co-production process

From the Stakeholder and co-production process a set of principles and evaluation criteria, was drafted to evaluate the potential adaptation pathways and development possibilities for the area. The principles were furthermore developed to ensure that the input from stakeholders also remains incorporated in the future DAPP steps. The following points were drafted:

- Water is a recreative resource
- Nature and natural areas should be extended and reinforced
- Potential developments should be inviting and integrated with the city
- Climate Resilient land-use
- Let nature contribute to the area-identity
- The river should be the city front, high standards for developments at riverside of the city
- Resilient from the start

Overall there was a focus towards the importance of resilient development and integration of nature in potential build environment. New development should incorporate nature based design, and account for future climatic changes such as to avoid new development in vulnerable areas. These principles have been included in the development and evaluation of potential future pathways as well in the development of desirable future scenarios for Skive.

Overview Adaptation Measures

Based on local vulnerabilities and land use a separate adaptation strategy was developed for each of the areas in Figure 5. Here, desirable future development scenarios are outlined and supporting adaptation actions. Vice versa, the development in each of these areas is constrained by the solutions available to adapt.

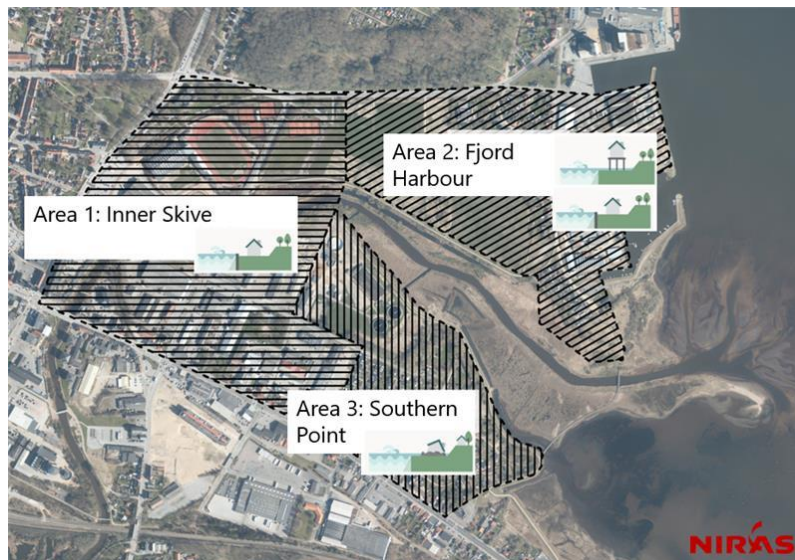


Figure 5. Inundation extent Skive using a static inundation model

The first area is located in the town of Skive with both apartments, offices, stores and supporting functions. Here, the current management features a protective approach at +2.5 m. Options for adaptation are constrained and a vertical limit was defined at +3.0 m to prevent the development of a walled fortress around the inner town. This means, that with incrementally increasing water levels, a decision will have to be made for a lock regulating the water levels or retreat from flood-prone areas. The process made the municipality realize the lock is an option, but that actions must be taken soon as it will affect other municipalities and protected nature.

The second area is less densely populated. As can be seen in Figure 2 for the physical description, the area behind the current flood defense is relatively flat. A setback line will be introduced behind which conditional development is possible. Between the setback line and the current flood defenses the land-use possibilities depend strongly on the adaptation measures implemented in the area. If the inner protection is not upgraded for example, more frequent inundation will limit the possibility for recreational development in the area. It is clear that over time the area will be used in such a way that it allows for periodic inundation as a result of water levels in the Limfjord.

The third area is located on the other side of Skive Å, where currently there is a low-lying residential area. In terms of development for this area either a full retreat from flood prone areas or a partial retreat with increased protection in the leftover areas is considered. Either way development will be limited to prevent increased exposure to sea-level rise.

Pathways

This paragraph will present the developed pathway maps. Considerations will be discussed in more detail in the discussion and conclusion chapter. In order to show the differences in development considerations the pathway map of area 1 will be shown. What can be seen in Figure 6 is that each of the pathways shows the implications for development and land use associated with the pathway. Depending on the pathway chosen, implications for development are clear. This allows for easy visual identification of pathway consequences.

What can be seen for area 1 is the necessity for an early decision point when deviating from the current situation. The decision to increase the current high water protection or improve emergency response are decisions that can be taken relatively late. The improved emergency response will require accommodation of current infrastructure to more frequent inundation. Establishing an outer lock, or the retreat from flood-prone areas both require a long lead time with deviating implications for current and new development. Therefore, even though the actual implementation of the adaptation measures will have to be implemented in the medium to long term, decisions on associated land use will have to be

explored in the short to medium term to avoid lock-in of investment or reversal of development choices due to an inability to adapt in the medium to long term. This means that these decisions will have to be integrated into the monitoring of the DAPP process.

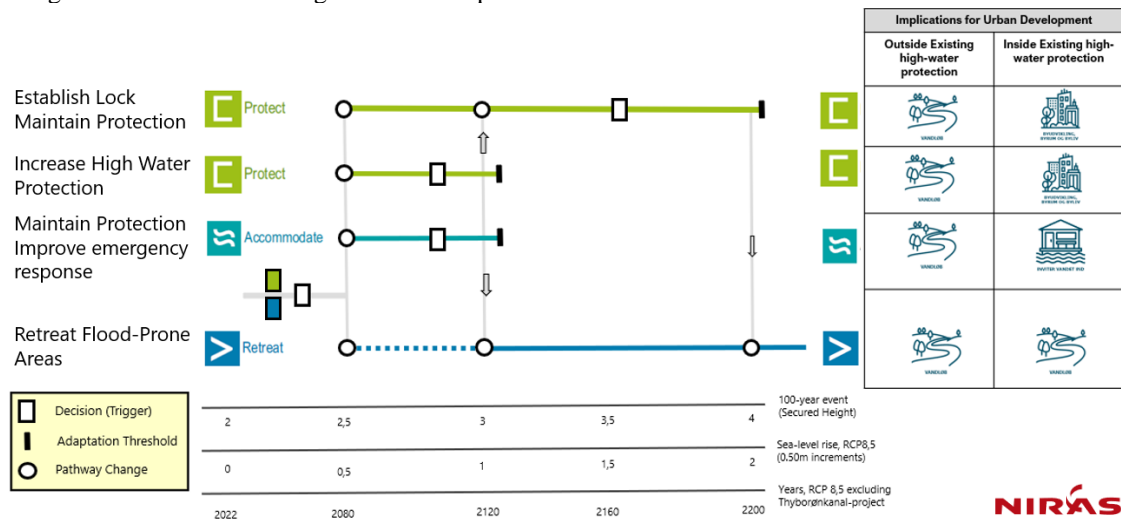


Figure 6. Pathways Area 1

For Area 2 it is expected that current management will be operational until +0.5m of sea-level rise, where a 1/100 year event corresponds to the current securing height of the embankment, +2.5m. When looking at Figure 6, there is an extensive green area that is within the current protective embankment and the proposed future setback line. Eventually this area will be developed in a way that allows for more frequent inundation in response to future sea-level rise in the Limfjord. In the meantime however, there is an opportunity to create recreational activity making use of the current protective embankment in the area.

The threshold has been set for +1.0m of sea-level rise, corresponding to a 3 m 1/100 year return period event. Either the existing embankment near the stream can be heightened, or emergency response can be improved where more frequent inundation will be accommodated for. Depending on the path chosen it has implications for both recreational, commercial and residential development in the area.

DISCUSSION AND CONCLUSION

With this project we aimed to gain additional insight into the DAPP process by investigating how a dynamic approach on climate adaption can frame the solution space and support urban development.

The project members of both the municipality, NIRAS and YTT Architectures learned a lot from the process. It was found that the implementation of the DAPP process was enabling stakeholders to get familiar with the uncomfortable truth of climate changes, and through it's clear steps it provides a great tool/method for organizing and getting through a large and otherwise complex project. The project required the participants to work beyond their regular scope, collaborating between different departments, holistic approach across departments, knowledge creation in departments and the creation of a mutual understanding of challenges to come.

This prepared and challenged the participants to look further into the future with an organized potential solution space. This enabled and empowered the municipality to make large decisions, knowing there are ways to reach their visions without increasing level of risk.

This takes time, especially changing from a static to dynamic planning mindset required for the DAPP approach. Therefore some decisions related mainly to the process, were hard and needed more time. Furthermore there is the challenge of keeping the knowledge within the Municipality over time.

Inner City

For the inner part of the city, a sequence of decisions is to be made where eventually either an outside solution is required regulating the water from the Limfjord into the city, or flood prone areas will have to be retreated. The timing of both actions is highly dependent on how the future unfolds and requires a significant lead time from the decision point to the implementation of the action.

For example, the first decision that needs to be made is to investigate if it is both allowed and possible to implement a lock or flood gate at this location due to environmental regulations. This needs to be investigated well ahead in time prior to the first threshold at +2,5m. Short term actions, such as increasing emergency preparedness can be taken however have immediate consequences for the development in the city. Instead, a temporary increase in crest height can also be implemented.

After discussions with the municipality it became clear that there is no interest in going beyond a crest height of +2,5m as living in a walled fortress is not considered to be 'a desirable future'. This means that from here, either an outside solution or retreat from flood prone areas needs to be considered.

Outside Area

For the area outside of the town, there is currently a protective structure of +2.5m. This area will feature the introduction of a setback line, in front of which no new development is allowed. The choice of adaptation measures over time will influence the land use possibilities in between the current protective structure and the proposed setback line. This also depends on the desired usage of the area.

For now, the usage of this area is largely recreational. If in the future the current protective structure is not adapted, more frequent inundation of the area will start to occur. The question for this area is therefore not if the protection level will suffice, but how long these measures will be maintained until the area is used to make room for the water during increasingly frequent periods of inundation. Again, adaptation choices have direct links to land-use and development possibilities, which is illustrated and anchored within the DAPP process.

Learnings

The duality of uncertainties in overall risk from both climate stressors and future land-use forces the integration of decision points into the adaptation planning. This means that measures within the DAPP need to be tailored based on area-specific vulnerabilities and the implications for future development and/or land-use.

Often the development of adaptation pathways focusses around the discussion of adaptation action, the development and evaluation of the pathways, following the initial steps of the DAPP process. For the Skive area however, many of the adaptation thresholds are still relatively far into the future. Again, this will also heavily depend on how future risk will change as a result of climate change. It is clear however, that action needs to be taken in the future. It is also clear that many of the adaptation options require a decision to be made well in advance of the emergence of an actual adaptation threshold.

This means that the focus of the study shifted from the development of adaptation pathways to the integration of future land-use and development choices into an adaptation pathways approach. Even though the implementation of these actions is still far ahead, research and eventually decisions on adaptation approach come much sooner and need to be specified within this adaptive plan.

This integration was enabled in the project through first identifying different subareas within the study area, and develop visions for future development. These were based on initial drafts from the architects and stakeholder involvement. Based on this, pathways were outlined that could support these developments. This allowed for each of the areas to gain insight into what (short term) decisions might constrain future adaptation choice once more transformative adaptation responses will be required to adapt.

Therefore on a strategic level the solution space will be updated for Skive as time goes onward by implementing the DAPP process reassessing adaptation portfolios in relation to socio-economic

changes and development in Skive. This touches upon some of the core elements of DAPP, where future lock-in and pathway dependability is to be identified and avoided. This will allow the town of Skive to gain insight into their possibilities of adaptation depending on how the city will develop, in parallel to uncertain changes in climate stressors.

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