Water NOT wanted - Coastal Floods and Flooding Protection in Denmark

Sørensen, Carlo Sass

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Die Universität Siegen beschäftigt sich seit über 15 Jahren wissenschaftlich und im Bereich der anwendungsorientierten Forschung mit dem Thema der Sicherung von Dämmen, Deichen und Stauanlagen und hat dazu mittlerweile fünf Symposien durchgeführt.


Neben den bewährten Themenkoerzepunktew, wie der Bemessung und Modellierung, Beiträgen zu Neubaube- und Sanierungsmaßnahmen, Fluss- und Seedeichen und der Verwendung von Baustoffen die bereits in vorherigen Handbüchern bearbeitet wurden, finden sich in diesem Fachbuch Beiträge zu dem Küstenschutz in Dänemark und dem Binnenhochwasserschutz in Österreich.
1 Introduction

For living and for leisure we see water as an asset. We are increasingly in favour of living close to water; be it a mountain stream, a tranquil lakeshore, a setting directly on the ocean foreshore or overlooking the ocean scenery. We use our proximity to water for many recreational purposes today. Water is nice!

There is a tendency for coastal migration, and a large part of the urbanisation and economic development is taking place in coastal regions throughout the world. This "coastal squeeze" means that we increasingly are exposing ourselves to the forces and hazards of nature in terms of coastal erosion, storm surges, coastal inundation, salination of aquifers etc. Whereas some regions already suffer today, challenges ahead seem immense with projections of sea level rise putting further pressure on our coasts.

Although Denmark is normally perceived as a country with a limited vulnerability towards coastal flooding, the country has experienced severe storm surges throughout history, and hitherto safe areas will become increasingly at risk this century as the climate changes. Historically a seafarers’ nation, Denmark has always been connected with the sea. From medieval time ports and quays have hosted activities related to maritime trades and harbour workers’ quarters. For the past two or three decades these areas have in many towns been rapidly transformed into high-end market housing and office facilities. With this transformation, more values have been put at risk and the local acceptance of floods has decreased from a “this is a natural consequence of living by the sea” to an explicit: Water Not Wanted!

This paper provides a brief overview of floods and flooding protection issues in Denmark (Ch. 2 & Ch. 3), the current legislation (Ch. 4), and discusses challenges in relation to climate change adaptation, risk reduction, and to potential ways of rethinking flooding protection in strategies that also incorporate other uses (Ch. 5).

2 Physical setting

Nestled in between Germany, Sweden, and Norway, Denmark faces the North Sea and the Baltic Sea. Kattegat, the Belts and the Sound act as transitional waters between the North Sea and the Baltic Sea, Fig. 1.
Except for the island of Bornholm in the Baltic Sea with some rocky shores, the country’s coastline predominantly consists of soft cliffs and marine sediments. The 7,300km coastline exhibits a large diversity of wave energy levels, water level variations, and marine landscape elements, with the many islands, fiords and embayments adding to the coastal complexity (Piontkowitz and Sørensen, 2008). To a large extent the Danish coastal landscape thus is a result of glacial erosion and deposition and of the varying marine environmental impacts since the Litorina transgressions (9-6,000 years BP) with net glacio-isostatic land uplift towards north and east and net subsidence in the southern part of the country (Mertz, 1924 in Noe-Nygaard and Hede, 2006), Fig. 2.

Today a net land uplift of approximately 2mm/y is found for the northernmost parts of Denmark, Fig. 3, and the averaged 20th century net mean sea level rise for the Danish waters is close to the global average of 0.15-0.18 m (Knudsen et al, 2014).

A large part of the Danish coastline is unprotected and the natural processes are allowed to redistribute the sediments. Still, there are more than 20,000 individual erosion protection structures along the coastline (groins, breakwaters, revetments etc.) and more than 1,100km of dikes (DCA, 2015).

This, of course, points to the fact that many coastal stretches are liable to erosion and flooding to an undesired extent from the property owners’ perspective. Dikes were until the mid-19th century mainly built to protect farmlands and only a few vulnerable towns had some kind of flood protection. Refer e.g. to Sørensen et al (1996) for an overview of the history of coastal engineering in Denmark.
3 Storm surges and flooding protection

Denmark and Germany do in many ways share cultural heritage and have a common storm surge history. In the Wadden Sea area storm surges and floods have been a part of life as long as these marshlands have been inhabited, and the local people built dikes that over time again and again proved insufficient to yield protection. Legends and written evidence tell of natural catastrophes destroying many towns and of people drowning by the thousands. The “man-drownings” in 1362 and in 1634 still exist in the collective Danish memory, too, as two of the worst floods on record, although information about their consequences seems sparse (GRAM-JENSEN, 1991; PIONTKOWITZ AND SØRENSEN, 2011). However, recent research on the morphological impacts shows that the 1634 storm surge did indeed have a large effect in the Danish Wadden Sea (FRUERGAARD ET AL, 2013).

Denmark avoided loss of lives in the 1953 and 1962 North Sea floods that caused devastation in the Netherlands and in Germany, respectively. Last time a sea flood in Denmark led to loss of life was during a rare summer storm surge 30 August 1923. 19 men working on construction of the Rejsby Dike on the Jutland Wadden Sea coast drowned.

On the North Sea coast of Jutland damages due to erosion and floods are not always separable in the historic records and have rarely led to loss of lives in this sparsely populated coastal area. Several events have had significant impacts on the coast like the 1825 and 1862 storm surges that led to breaches of the sandy barrier separating the Limfjord from the North Sea.

Along the shores of the western Baltic Sea the November 1872 storm surge still stands out with incredibly high extreme water levels in both Denmark and Germany (e.g. BAENSCHE, 1875; BORK AND MÜLLER-NAVARRA, 2009; COLDING, 1881; JENSEN AND TÖPPE 1990; MUDERSBACH AND JENSEN, 2009). In Denmark, large low-lying areas of Sealand, Lolland, Falster, Funen and Jutland were flooded, and about 80 people drowned on Lolland and Falster where there were no higher grounds to escape to. Several studies have modelled the event or have given estimates of the return periods of the experienced water levels. From a sedimentological record in beach ridges, CLEMMENSEN ET AL (2014) interpreted the impacts and water levels to be unprecedented in 4000 years. Back in time the inner Danish waters have experienced severe floods. Little evidence exists of such events being even near the 1872 extreme water levels, however, or having any comparable impacts over wide areas.

In the following, the principles and extent of coastal flooding protection in the Wadden Sea, on the central North Sea coast, and in the inner Danish waters are presented together with selected regional storm surge accounts. Refer to PIONTKOWITZ AND SØRENSEN (2011), SØRENSEN AND PIONTKOWITZ (2013) and SØRENSEN ET AL (2013) for information on extreme water level statistics, and historical floods and their spatial variation in Denmark.
3.1 Wadden Sea coasts

Historically, the Danish Wadden Sea dikes have been notoriously badly kept leading to numerous flooding accounts e.g. in the town of Ribe. The dikes were mainly summer dikes protecting the marshlands and for centuries the inhabitants of Ribe were reluctant to financially support the construction of dikes for their protection. The constructions of proper dikes were dependent on external financing in other areas of the Wadden Sea as well.

After severe storm surges in 1909 and 1911, respectively, proper dike construction was initiated around Ribe and elsewhere in the Wadden Sea over the next two decades. Succeeding two storm surges in January 1976, Denmark and Germany agreed on the construction of an advanced second dike line in front of the Højer-Vidå area (original dike built 1861). The 1976 surges did not lead to dike breaches of the Højer-Vidå dike but inhabitants of the town of Tønder and other low-lying areas were evacuated. The 12.2km long Danish-German dike, consisting of approximately 5 Mio. m$^3$ sand and clay (Da.: klaeg), was inaugurated in May 1982 and is by far the largest dike in Denmark (ANDERSEN, 1998; ANDRESEN ET AL., 1982). The 24 November 1981 storm surge led to some dike breaches, and during the 3 December 1999 storm surge the Juvre dike breached and several other dikes were damaged, Fig. 4.

The construction of the Danish Wadden Sea dikes follows a classic design (PULLEN ET AL, 2007) with a sand core, a top layer of clay, and a grass cover, Fig. 5. Depending on the dike exposure to waves, the front slopes of individual dikes range from 1:2 to 1:10 and the back slopes between 1:2 and 1:3. Traditionally, the Danish Coastal Authority (DCA) has been in charge of yearly inspections of most of the Wadden Sea dikes giving maintenance advice to the local dike committees. Subsequent to storm surges dikes are also inspected for damages. DCA has published details of construction of all dikes including year of construction/reinforcement, price, information on sluices, photos etc. (PIONTKOWITZ ET AL, 2011) which together with information on water level statistics (SØRENSEN ET AL, 2013) and wave loads, enter an overall assessment of the dike safety (JENSEN, 2011), Fig. 6.

Fig. 4: Breach of the Juvre Dike (left) and repairs on the Rejsby Dike, 1999
In general, the dikes are in good condition and, depending on their purpose for protection, are evaluated to yield protection for a 20-500 years extreme water level event, which for the majority of the dikes exceeds the projected safety level. However, the dike safety may be insufficient when taking into account the number of inhabitants in each protected area and increases in tidal amplitude, mean water level, storminess, and extreme surge levels, respectively, under climate change scenarios. Dike breach and inundation modelling have been performed for several of the Jutland marsh areas to aid the planning of evacuation routes etc. (CHRISTENSEN ET AL, 2013). Looking ahead, probabilistic approaches that take into account also river run-off in prolonged periods of high ocean water levels will yield more information on the hazards and risks and lead to more refined methods of evaluating dike safety and flooding risks in the Danish Wadden Sea area.
3.2 Jutland west coast

On the central North Sea coast of Jutland coastal erosion protection dates back to around 1875 where the construction of groins was initiated south of Thyborøn to limit the erosion in front of the Limfiord barriers. Previously only low sand dikes that mainly served to decrease the Aeolian transport existed, Fig. 7.

Fig. 7: An old sand dike on the Limfiord Barriers, 1896

In Thyborøn and further south on the coast at Hvide Sande and Thorsminde, harbours were constructed in the late 19th and early 20th centuries. At Thyborøn there still is an open canal to the Limfiord, whereas at Thorsminde and Hvide Sande sluices regulate the water levels (and/or salinity) in the west Jutland fiords of Nissum and Ringkøbing that are only separated from the North Sea by narrow sandy barriers. For centuries people had to move further inland as the coastline receded, but mainly due the harbour constructions with increased erosion on some parts of the coast, large protection schemes were initiated to decrease natural erosion rates on the coast and to protect the low-lying hinterlands from flooding. Large flooding of houses has been avoided in the past with only minor recent dike and dune breaches in 1981 and 1999, respectively.

Today's erosion has ceded due to sand nourishments of 2-3 Mio. m$^3$/y along the 110km coastline since the 1980s that work in combination with (mainly) artificial dunes and dikes for flood protection, Fig. 8. In front of Thyborøn, a large sea dike protects the town to an estimated 1000 year event and along the rest of the coast the safety is evaluated at 100 y. This of course means that there is a genuine risk of dike/dune breaches along parts of the coast. For many years the rhetoric/practice of the DCA was that only permanent residences were the aim of protection, but this has now changed. Along with the success in decreasing erosion rates, thousands of holiday houses with a high value have been built along the coast. Due to fairly strict regulations in Denmark most of the holiday houses are placed at some distance inland not in immediate threat from erosion, but they may pose a challenge to the flood protection.
The safety of the dunes is evaluated from a combination of sea elevations during storms and experiences of maximum erosion during past events which include wave run-up and alongshore variation in the position of the offshore bars. In general, a dune 40m wide and 5m high is used as minimum criteria for protection against flooding, provided that there is sufficient time for emergency repairs between consecutive storms, Fig. 9.

Fig. 8: Dike and artificial dunes north of Thorsminde (left), groins and sea dike at Thyborøn (top right), and storm erosion and dune repair north of Hvide Sande

Fig. 9: Principles of dune safety against flooding, Jutland west coast
3.3 Inner Danish coasts

Along the inner Danish coasts, defined here as all except the Wadden Sea and North Sea coasts, flood occurrences are more complex and flood protection is more fragmented. Nevertheless, floods have occurred throughout history and have adversely affected people in many areas. By large, however, the inhabitants of the many coastal towns seem to have coped fairly well and with many of the medieval town centres placed wisely about a meter above the highest surge levels experienced. As previously mentioned many flood-prone parts of towns contained harbour workers’ quarters and maritime related trades (HARNOW ET AL, 2008). With a rising sea level and local subsidence in some areas, many of the old town parts that hold the cultural heritage values and identity increasingly become at risk. In connection with the old town centres, areas have been urbanised in the last half-century in low-lying areas some of which contain flood protection and some do not. A comparison between the late 19th century and today often shows that much of this coastal urbanisation has taken place in previously unoccupied areas like bogs and meadows. In addition, since 1930s the Danes have been in favour of owning a holiday house, or a beach shack, by the coast, Fig. 10.

![Holiday houses/beach huts on the island of Ærø](image)

With the increasing wealth in society these shacks have in many places transformed into more fashionable holiday houses. From a flooding point of view this is unfortunate since many of these lie behind beach ridges, being themselves a result of extreme events, as their only protection. In other places dikes have been built for protection. Some dikes are well constructed whereas others lack sufficient design measures and maintenance for flood protection. Only in the last decade or two, assisted by floods from extreme events, has the exposure and vulnerability in the inner Danish waters regained focus.

The 1872 Baltic Sea storm surge led to the construction of large dikes at the islands of Lolland and Falster in particular (e.g. BRANDT, 1997; COWI, 2010; HANSEN, 1879; JENSEN AND TÖPPE, 1990; LOVIDENDE, 1873; OUMERACI ET AL, 2012), Fig. 11. Later the extreme water levels from the 1872 event have been used in design criteria for dikes around land reclamation south of Copenhagen for industrial purposes in 1964 and in relation to dike enforcement on the western part of the island of Amager, Copenhagen, in 2009-2012. In most other areas the protection level is much lower and the extremity of the event still puzzles the Danes in relation to flood protection. As a reply to a screening performed by DCA based on the 1872 flood levels and +0.25m of sea level rise, AABENRAA MUNICIPALITY (2011) stated: “With an extreme water level of 3.62m, as used in your screening, there is not much else to do than to save valuables - turn off the power and leave the exposed areas”. Protection cannot be granted everywhere against any potential extreme event in the future!
Fairly extensive floods occurred in November 2006 leading to more than 4000 houses being damaged in the Kattegat and Belts areas. Floods were also experienced during the 5-6 December 2013 storm (Eng.: ‘Xaver’; Da.: ‘Bodil’), mainly in the Limfjord area (Fig. 12) and on the northern part of Sealand.

During both events the extreme water levels were record breaking in some long tide gauge records but the incidents were treated differently in the media and in public. There are of course several reasons for this. The 2006 flood event caused damage in many of the towns on Funen and in east Jutland and served as a warning about the nature of extreme events; about preparedness when warnings were issued, and about greater awareness of extremes and climate adaptation when planning at the coast. The event also produced many initial thoughts about flood protection and on how to minimize damages in society; and it led to flood protection efforts in many areas. In this sense, the obvious adverse effects of the flooding to people, to property and to society were locally transformed into something positive in relation to addressing the exposure and vulnerability towards floods.

The Xaver-floods (and coastal erosion) mainly struck other parts of Denmark than in 2006 and were in some areas quite severe. The tide gauges at Hornbæk and Copenhagen recorded the highest ever water levels (series from 1890-2015). Many houses became uninhabitable for quite some time and some still are. Different to the 2006 event the floods

Fig. 11: Section of the east coast of Falster where holiday houses were built behind the dike between 1964 (left) and 1985 (From BRANDT, 1997)

Fig. 12: High water levels in the town of Lemvig, the Limfjord, during Xaver 5 December 2013. Note the flood protection wall winding along the harbour front
were perceived more as a consequence of climate change than being due to an extreme event; the pressure from inhabitants in the affected areas towards policy- and decision-makers was far more articulate and organized, and the call for fast actions has been very pronounced.

Which concrete solutions will follow and how large a part this incidence will play in the future regional and national flood protection policies is hard to say as the affected areas are still in the aftermath of this extreme event regarding recovery and negotiations of flood protection solutions.

Another part of the story is that most of the affected areas have experienced floods before. For instance, in 1921-1922 three storm surges struck the coasts during a two month period. These flood events are fairly well documented (MINISTERIET FOR OFFENTLIGE ARBEJDER, 1922), Fig. 13, but occurred a long time ago!

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**Fig. 13:** Floods in identical locations in 1921 and during Xaver, 6 December 2013 at Frederikssund (left) and at Helsingore, Sealand. Sources: mx.dk (top left), helsingometavis.dk (top right) and MINISTERIET FOR OFFENTLIGE ARBEJDER (1922)
For coastal flooding protection in Denmark a “those who benefit must pay” approach applies. Property owners pay for their own protection. For historic reasons, however, the Danish government has played a larger role in financing and maintaining dikes, dunes, revetments etc. along the central North Sea coast and in the Wadden Sea area. Two reasons are that storm surges are more violent in terms of extreme water levels and waves, and the aforementioned construction of ports along the North Sea coast a century ago.

Since 1983 the national government has had joint agreements with several municipalities along the North Sea coast regarding coastal protection with a share of up to 90% (app. 11 Mio. €/y) (DCA, 2013). The national engagement in Wadden Sea dikes, their reinforcement and maintenance are negotiated *ad hoc* and are currently limited to inspections and advice regarding their safety.

The coastal protection in Denmark is regulated through the Coast Protection Act (TRANSPORTMINISTERIET, 2009). Anyone interested in protecting his/her property must apply, and permission is granted only when constructions are technically optimised and negative effects on neighbouring stretches are minimised. Several additional conditions about the necessity for protection, economic considerations, respect to nature, and free passage along the coast must also be met; the property in Fig. 14 e.g. reflects conditions that are not met regarding economy and nature. Further conditions may be requested regarding maintenance etc. DCA (2011) outlines a national coastal protection strategy that favours joint solutions for longer stretches of coastline and the use of sand nourishments.
where appropriate. The Coast Protection Act is one of several laws regulating the coastal zone, Fig. 15.

To one owner, or several owners agreeing on a specific coastal protection scheme, the application procedure is fairly straightforward: If you have a need, a sound protection project, and finances available you may proceed. In relation to flood protection schemes (and larger erosion protection projects) disagreements are usually the case.

If interests about the coastal protection and the need, the design, the economic shares etc. differ between the land owners, the regional authority (76 of 98 Danish municipalities have a coastline) may be approached, Fig. 16. The municipality, which may be a land owner them self, then has to test the case; involving all land owners who may potentially benefit from the protection, and decide whether to proceed. The municipalities also have the opportunity to raise a case and can force a project upon the landowners. However, they are very reluctant to do so. Despite the intentions of the law, very few projects have come around this way without a very determined municipality or local capacities in mediation. In brief: The law does not really work in these cases.

In general, the municipalities are not to favour some residents ahead of others, meaning that some common interests for the entire community must be present: recreational values, infrastructure, cultural aspects etc. Hereby a few municipalities have been successful in the implementation of broader flood protection solutions, whereas the majority are still discussing what to do now and to whom the bill shall be addressed.

**Fig. 15:** Legislation in the Danish coastal zone (NM = Nautical Mile)
Currently a national coastal analysis is being prepared that looks into the hazards and risks of flooding and erosion for the entire country which, together with legal aspects, may initiate a political debate about the future of coastal protection, climate adaptation and risk mitigation in Denmark.

Concurrent to this the first period of implementation of the EU Floods Directive (2007/60/EC) is being finalized and preparations are being made for the second period. In Denmark, 9 coastal risk areas including 21 municipalities have made risk reduction plans based on hazard and risk maps produced using the XtremRisK-method for Danish conditions (Burzel and Oumeraci, 2012; DCA, 2013B; Oumeraci et al, 2015; Piontkowitz and Sørensen, 2011; Piontkowski et al, 2014). In addition, all 98 municipalities have made individual climate adaptation plans (DG, 2012) focusing on risk reduction from floods due to extreme precipitation, storm surges, and the sewer systems.

Regarding projections of sea level rise (SLR) (and other factors) due to climate change there are still no official Danish political statements for planning purposes. For the EU Floods Directive, SLR of 30cm (2060) has been used together with an unofficial 80cm scenario for 2100. For the climate adaptation plans, the advice is to apply 25cm (2050) but other numbers may be chosen by the individual municipalities. This, of course, yields a varied picture of the challenges ahead between municipalities. From the scientific community some central estimates for Denmark and the Baltic area were published recently (Grinsted, 2015; Olesen et al, 2014) which may over time align Danish approaches to SLR among decision- and policymakers.

Denmark has for decades had a storm surge emergency relief fund where every house owner pays app. 4 €/y through their insurance. Due to the floods experienced especially in 2006 and 2013, the payouts exceed the income to the fund. Voices have been raised politically about the fund’s strict rules for funding as well as being too slow in paying out for flood damages etc. The relief fund is currently undergoing revision. Central to the revision of the relief fund, to the climate adaptation plans, to the EU Floods Directive, to the coastal analysis, and regarding flood protection under the Coast Protection Act lays the question: Who is to blame about floods and climate change impacts and who shall pay?

**Fig. 16: Procedure when landowners do not agree about a coastal protection scheme; see text for further explanation**
5 Discussions

The spatial division between the Wadden Sea, the North Sea coast and the inner Danish waters reflects fairly well the flood protection history and the different challenges faced today and in the future. Traditionally, the national emphasis has been on the protection of low-lying marshlands and on the combined erosion and floods protection along the Jutland west coast together with dikes on the islands of Lolland and Falster succeeding the 1872 Baltic Sea storm surge. The purposes of protection were more in favour of safeguarding agricultural and trades’ interests than is the case today. Now the safety of the inhabitants, economic values of housing and infrastructure, and cultural assets are in focus. In general, the focus is currently turning towards values and assets along the coasts of the inner Danish waters. Whereas coastal protection on the abovementioned coasts dates back a century or more, only recently the lack of coastal flooding protection measures has gained attention due to several extreme events in the inner Danish waters in recent years. The incorporation of climate change factors is only slowly being made in planning procedures and regulations.

Currently a number of initiatives are on their way in order to deal with floods in Denmark (Ch. 4) which hopefully will advance Danish approaches and measures for flood protection, climate adaptation, risk reduction and provide a platform for better decision-making. Regarding the entire coastline, the country also needs to have the important discussions about what to protect and at which costs. This will include debates about potential planned retreats in some areas and the potential expropriation of properties. Denmark needs to address these matters, too, to overcome some of the tedious arguments about who has the responsibility and financial will to pay for flood protection and climate adaptation.

The risk awareness also needs to be raised in the public. To the unfortunate people being flooded it is too late. This may be built upon some of the good bottom-up initiatives that have surfaced in recent years from local groups and from specific municipalities.

With climate change Denmark will experience more severe storm surges in the future and must transform this knowledge into concrete solutions for flood protection. In the Wadden Sea and on the North Sea coasts this may translate into larger dikes and more sand, respectively, whereas the traditional engineering protection solutions do not seem sufficient at many inner Danish waters’ coasts, and especially where old town centres become at risk. One may of course look towards e.g. Hamburg, Germany, for inspiration, but still the solutions must fit into a Danish context to preserve the cultural heritage values of the towns. And yes: the Danes also want the proximity to water in the future. The transformations of old harbour and quay areas also in many places are positive stories about opening the towns towards the sea. Lemvig, Fig. 12, is one small example where the renewal of the flood protection wall has immensely raised the aesthetic and recreational value of the area without jeopardising its purpose of protecting the town from flooding.

The author is in no doubt about the value of more transdisciplinary collaboration in relation to flood protection and climate adaptation. Urban development is not cheap, but the extra
investments for ‘flood-proofing’ Denmark will not be unaffordable if seeking the right solutions that involve more than just the erection of sea walls and flood protection walls.

Multipurpose solutions are slowly emerging in both Denmark and abroad. Due to the infrastructural complexity between e.g. the flood-prone Danish coastal towns, a ‘one-size-fits-all’ approach is not viable. Some risk reduction efforts are more urgent than others but, in general, there is time to seek the right solutions in collaboration between coastal and hydraulic engineers, town planners, architects, local residents etc. For inspiration and to challenge the usual engineering approaches, just a few sketches may point in a new direction, Figs 17 & 18. Other ideas like villas with pavements and sewers that all float during floods, or, giant (silicone) implants under the old town centre to lift it above future surge levels may sound too futuristic and crazy. Nevertheless, urban flood protection schemes are foreseen to transform into multipurpose uses and to include new and alternative solutions as waters encroach on our shores. This is a part of re-thinking the ways we may inhabit the coastal zone also in the future.
6 Literature


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