The Effect of Beach Buildings on Decadal Dune Volume Development

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Abstract. Dutch beaches are increasingly urbanized with both permanent beach pavilions and seasonal sheds and holiday houses. The effect of these buildings on long term dune development between 1999 and 2024 is studied in this paper along ~ 100 km of coast on the outer delta in the south western part of the Netherlands.

A total of ~ 7000 beach buildings have been manually identified in this period based on satellite images and the time line function of Google earth desktop. The effect of the buildings is determined and analyzed at 477 cross-shore profiles with dune volumes and properties like dune toe, top and heel based on airborne lidar datasets of 1999 and 2024. On natural beaches the dune toe position is derived from profile information, whereas on urbanized beaches near buildings the dune toe is based on the location of the buildings.

Yearly volume changes at the profile locations vary between -10 m^3/m/y and up to 40 m^3/m/y. The results indicate that smaller and standalone buildings allow for larger variations in dune volume changes and suggest that larger buildings and connected buildings impede natural dune dynamics which could impact coastal resilience in the long run.

Keywords: Sandy coast · Urbanization · LiDAR datas

1 Introduction

Sandy beach-dune systems are increasingly urbanized [1, 2] in certain countries with beach pavilions and other recreation/holiday buildings along the dune toe and in the dunes (Fig. 1). In the Netherlands a significant increase in beach sheds, buildings and pavilions has been observed in the last 20 years [3]. Although beach pavilions are part of the Dutch landscape since the 1950's, more and more local municipalities consider.

the beach-dune system as an active economic development zone. This results in an increase of year round beach pavilions and seasonal smaller buildings like beach sheds and holiday houses.

Buildings affect local wind patterns [4, 5] along the dune toe which influences both the local morphology [6] and the shoreward sand transport patterns. In the long run

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Fig. 1. An example of a Dutch urbanized beach with buildings along the dune toe (©Sander Vos).

this can lead to non-uniform dune development [7] and can impact coastal resilience. Especially when dunes cannot keep up anymore with the expected sea level rise [8] due to increasing urbanization of our coasts, these problems can pose increasing challenges for the future.

Recent research [5–7] has mainly focused on building influences on a local scale but little information is available on larger spatial and temporal scales. In order to study the effect of buildings on a larger spatio-temporal scale, the dune development of a stretch of 100 km of Dutch coast is here analyzed over a 25 year period.

2 Research Method

2.1 Research Area

The influence of buildings on local dune development is researched on the outward delta of the Dutch coast (Fig. 2A) which is located in the south-western part of the Netherlands. The study area consists of 100 km of natural and urbanized sandy beach dune systems. The coastline orientation ranges from N-W-S with dominating NW and SW orientations. A total of 477 dune cross-shore profiles are analyzed (Fig. 2B). For the profile-locations a subset (only the sandy profiles) of the Jarkus (Dutch coastal dataset) cross-shore profile dataset [9] has been utilized. The average distance between profiles is about 200–250 m.

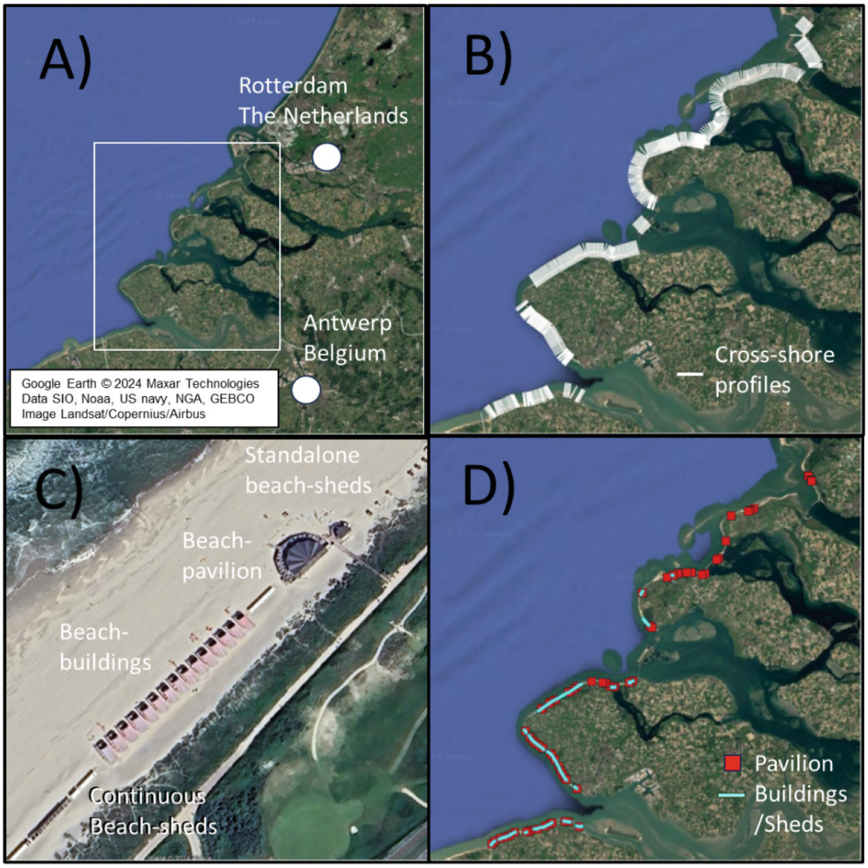

Fig. 2. A) Study area (51.632˚N, 3.896˚E) along the Dutch coast. B) Cross-shore profiles used in the dune analysis. C) Example of different beach buildings and configurations; Standalone and continuous beach sheds, beach houses and beach pavilions. D) Detected beach buildings (2024) along the Dutch delta.

2.2 Beach Buildings

Beach building locations have been determined manually with the Google earth desktop [GED, 10] software which provided the largest available satellite/aerial archive with submeter resolution. Buildings have been characterized based on size (Fig. 2C). The smallest beach sheds are used typically for personal storage of beach objects (like seats), while the medium beach houses are used as (overnight) holiday homes. Both buildings are seasonal and are removed during the winter storm season and can either be placed continuously (i.e., side to side) or standalone on the beach. Finally, the largest buildings are year-round beach pavilions.

Buildings have been counted either separately (standalone buildings and pavilions) or per unit length. For the unit length it was assumed that beach sheds are on average 2 m wide and beach houses on average 3.5 m wide. Figure 2D gives an overview of all beach seasonal (shed/houses) and permanent (pavilions) buildings along the Delta coast in 2024.

The history of the buildings was determined using the time-line function of GED. For each location the first available detection was based on the first available satellite image with recognizable buildings. On average first detections could be done using satellite images between 2003 and 2005, depending on location.

2.3 Dune Properties

Dune properties like dune toe, top and heel positions were based on a modified scheme of [7] and [9] and dune profiles of 2024. Dune properties were kept constant through time. On natural beaches the location of the dune toe is determined with a modified derivative profile detection method; the first location from the seaward side with a 1st and 2nd derivative less than 0.01 (m/m and m/m^2) or a maximum dune height profile of 6 m. For urbanized beaches with buildings detected within the neighborhood of the profile (distance between profile and buildings less than 20 m) the dune toe is moved 5 m towards the dune beyond the location of the buildings.

The dune top is defined as the first dune top beyond the dune toe that is larger than 6 m and with a prominence larger than 0.5 m. The prominence of the peak indicates how much the peak stands out and is defined as the vertical distance between the peak and its lowest surrounding contour line. Finally, the dune heel (end of the dune) is defined either as either 200 m landwards of the dune top or the end of the profile.

Dune volumes were calculated as the total volume of the dune between the dune toe and dune heel location. An example of detected dune properties is shown in Fig. 3.

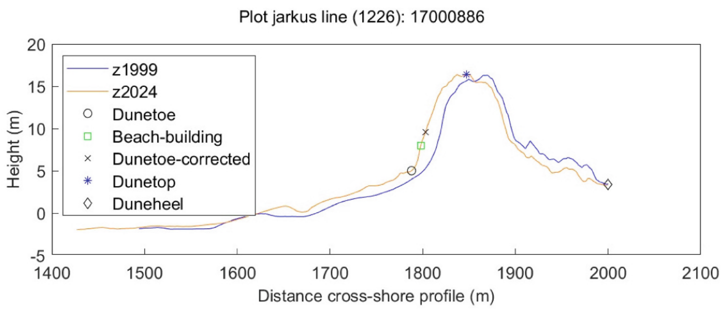

Fig. 3. Example of detected dune properties. The plots shows a cross-shore profile of 2019 and 2024 at Jarkus line 17000886. On the 2024 profile the position of the dune toe based on the derivative method, detected beach building, corrected dune toe, dune top and dune heel are indicated.

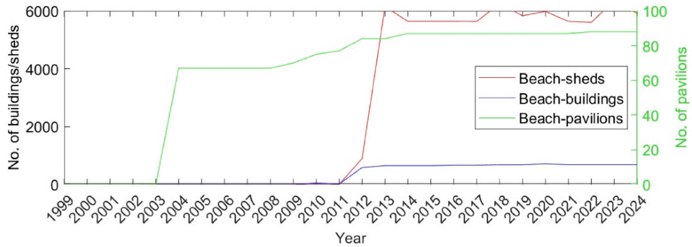

Fig. 4. Timeline of the number of detected beach sheds, buildings, and pavilions in the Dutch outer delta from 1999 till 2024.

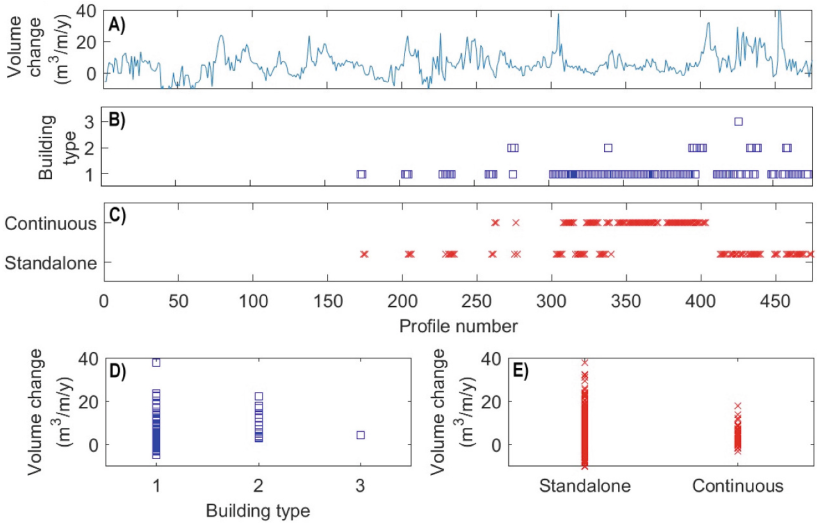

Fig. 5. Yearly volume changes (A) from North to South along the cross-shore profiles in the Dutch delta, with corresponding building type (B) [1) Shed, 2) Beach house and 3) Beach pavilion] and configuration (C) [Continuous or standalone]. Panel (D) and (E) show the relation between detected volume changes versus building type and building configuration.

3 Results

3.1 Beach Buildings

Figure 4 shows an overview of the number of detected buildings through time with a maximum of about 6000 sheds, 600 beach houses and 90 beach pavilions in the Dutch outer delta in 2024. The detection of pavilions is possible from around 2003 when the first high resolution satellite images were available. Detection of smaller buildings is hard in this period as images are only available from the winter period. High resolution summer period satellite images are available starting from 2013 after which beach sheds and buildings can clearly be identified.

Figure 5 shows the yearly volume changes (A) per cross-shore profile from north to south with the detected beach building type (B) and configuration (C). Yearly volume changes range between -10 m^3/m/y (i.e., dune loss) to 40 m^3/m/y while most beach buildings are found between profile 300 and 477.

In conclusion panel 4D and 4E show that building type and continuity have an influence on the observed range of yearly dune volume changes. Smaller and standalone buildings show a larger variation in dune volume changes than larger and continuous connected buildings. This indicates that buildings limit natural dune dynamics which could impact coastal resilience in the long run.

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