Build a 3D port model and demonstrate automated change detection

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Background

The objectives of WP4 Activity 4.4 were to demonstrate and evaluate the use of 3D visualization/models in navigational aids display and to demonstrate automatic change detection of topographic ENC features in harbours.

To attain the objectives, a 3D model over a selected harbour should be constructed and a suitable 3D viewer with simple navigational facilities acquired. The 3D viewer would then be used for the evaluation of the usability of 3D visualization in port navigation. Finally the 3D model should further be used for a demonstration of automatic change detection.

1. Introduction: Why 3D?

Mistakes in navigation are not seldomly the cause of shipping accidents. This type of accidents is most often classified as "human error" as much of the time no malfunctions in any of the technical systems on-board it is to be found. In 2007 the Chinese container ship *Cosco Busans* struck the San Francisco-Oakland Bay Bridge in heavy fog. She was conned by a local pilot with 25 years of experience in the area. No malfunctions in equipment were found. In 1999 the Norwegian high speed ferry *Sleipner* crashed on a rock in darkness and bad weather. The two experienced officers had for a few seconds been inattentive to the course steered and when they looked up the ship had slipped off her course. They did not manage to recover their orientation before they struck the rock. No malfunctions in instrumentation were found. And in 1989 the tanker *Exxon Valdez* grounded during night spilling huge amounts of oil. For some unknown reason the watch officer waited a few minutes too long to make a crucial turn. All navigation instruments were working. Just to mention a few.

In all of these cases the presence of all modern navigational aids did not stop the bridge crew from losing their orientation for a short but significant period of time. Why do highly trained bridge officers serving on technically sophisticated ships, often in areas well known, lose their orientation?

What if it is not "human error" but instead inherent problems with the user interface of the navigation system?

1.1. Navigation

Navigation is the aggregated task of finding where you are (position fixing) and establishing a direction to go (course setting). When moving around in our everyday environment humans base way finding decisions on information from our senses, mostly the vision (so called bottom-up processing) and from experience and learned skills (top-down processing). The input to the visual perceptive system is a 2D picture of the surrounding world projected upside-down on the retina, at the bottom of our eyes. This picture is then interpreted by higher order processes in the brain: turned right side up, depth cues like linear perspective and occlusion is used to transform the 2D picture into the experience of a 3D world (Wickens & Holland, 2000). As time goes on we get very skilled at acting on the world from this *egocentric perspective*.

The egocentric view is the one most of our everyday decision making is based on. Observe for instance yourself the next time you walk through a crowded shopping mall, avoiding colliding with people. Way finding based on visual input is fine as long as long as the area is not larger than what can be overviewed from the point you where you are. But if the area becomes larger than that we need help from some kind of tools. If you are well known to the area you will use an inner cognitive construct, termed *mental map* by Toleman (1948). This inner map is built up by experience in a three step process of acquiring spatial knowledge as we learn to know a new area (Siegel & White, 1975). First we acquire *landmark knowledge* as we learn to recognise particular buildings or other unique features of the environment. When we have learned to group together landmarks into paths we have reached the level of *route knowledge*. And finally, at the highest level, we reach *survey knowledge*, which is the level where we are able to infer short cuts through places not visited before and make judgements on distances based on the cognitive map.

The mental map is the most common cognitive tool we use for navigating areas larger that we can overlook. And as fog or darkness limits our vision these areas can become very small. The precision of the cognitive map has been questioned by Barbara Tversky (1993) to the point that she instead wants to call it a cognitive collage to make explicit the inherent mistakes caused by limited memory and misconceptions and a warning to place too much trust to the mental map.

If we look at external cognitive tools to help us navigate the world, we find aids like the not quite useful bread crumbs in the fairy tale of Hans and Gretchen, roads and signs in the traffic environment or buoys and cairns as in the maritime domain. But the most commonly used navigational aid of all is *the map*.

1.2. The Map

The map is at least 3500 years old. As a way-showing device it is built on the somewhat surprising concept that we observe ourselves and the world from above, from an *exocentric bird's-eye view*. To locate our position in the map we need to make comparisons of angles to known objects in the world and their representations on the map which involves comparing our egocentric view of the world with an imagined egocentric view from the proposed position on the map. When the imagined egocentric view corresponds to the real view we have found where we are in the map. These are cognitively quite demanding operations that tax our limited working memory to the fullest. We call these operations *mental rotations*, a notion that was investigated by Shepard and Metzler (1971). Especially demanding are these operations when you are southbound on a north-up oriented map and first need to mentally rotate the map 180 degrees around the vertical axes and then 90 degrees around the horizontal axes. Most of us know the situation when we in an unknown city have to turn the map upside-down to figure out if it is to the left or to the right we should turn in the coming street corner. Although the problems associated with navigation using maps, the exocentric bird-eye view is the most commonly used navigational aid, maybe because its ability to grant instant overview. One can for instance acquire immediate survey knowledge without passing the stages of landmark and route knowledge, simply by climbing up in a high building or looking at a map.

The hypothesis tested in this project is that by presenting the map in an egocentric 3D perspective, we can remove the need for making mental rotations and thus make faster and more accurate decisions.

1.3. The egocentric 3D map

What is an egocentric 3D map? If you want to remove the need for doing any mental rotations your map should look just like the real world in front of your eyes. In Figure 1 you can see a sphere and a cube depicted on three different maps. If you look at the two objects facing south their internal relationship will be reversed on a *north-up* map (the one to the left). Then pretend that this was a city plan and you were to turn right after having passed the green cube. This right turn will be a left direction on the north-up map! By turning the map around so that what is in front of you is also up on the map (called *head-up* orientation, the middle map in Figure 1) the need to mentally rotate the map around the vertical axes is removed. Left and right directions on the map and in the real world now coincide. The final transformation is to remove the need for a 90 degree rotation around one of the horizontal axes (the map to the right). You now have an *egocentric 3D map*. This is for instance beneficial to see topographic features like heights and shapes of buildings or cliffs not visible from the orthographic perspective of traditional maps. Like for instance if the red object is a sphere or a cone.

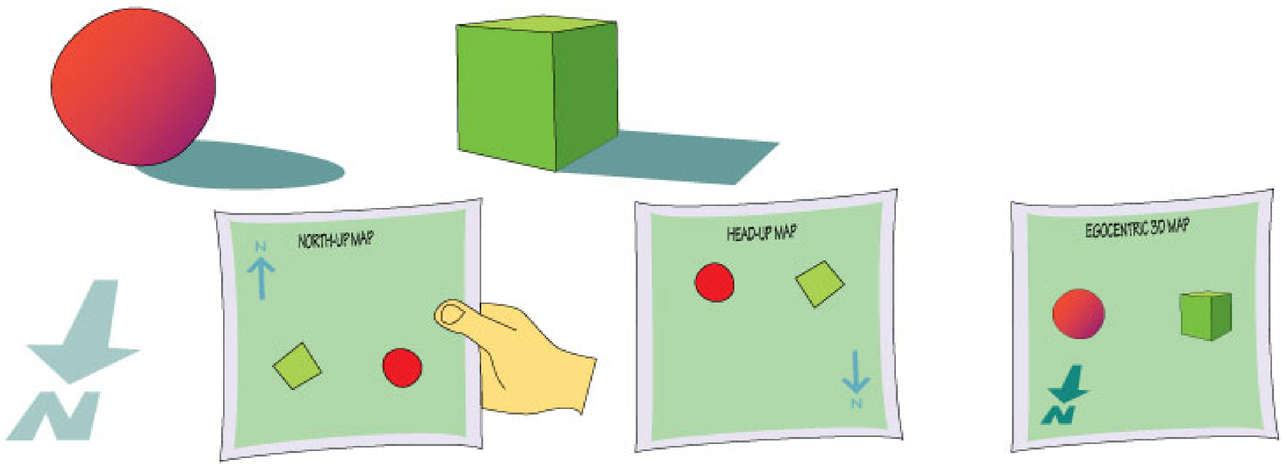


Figure 1: A sphere and a cube. If you look at them facing south their internal relationship will be reversed on a traditional north-up map (to the left). By rotating the map head-up (middle) you will remove one mental rotation. By presenting them in an egocentric 3D view (right) you have removed the need for any mental rotation. Illustration by T. Porathe.

Before the nautical charts became common on-board ships verbal descriptions called sailing directions was used. But to be able to tell different islands apart words alone were not enough and very soon these sailing directions became illustrated by wood cuts depicting the special features of important landmarks, like the French island Île d'Ouessant ("Ushant" in English) in Figure 2.

Item, when you are northwest and by north of Vshant then maye you see through the poynte which is to the southwards of the maine Iland, and when you are of of Vshant northwest and by west, then is that poynt shutte in on the shore.

Item, when Vshant beares north northwest from you, then doth it appeere like as it is heere aboue demonstrated.
Item, when you are off of Vshant Northwest and bywest, or west northwest then lyes there a great Rocke of the northeast pointe, but you cannot well see through betwixt the Rocke and Vshant from thence. And alongst the

Figure 2: A coastal view incorporated in a sailing direction over the French west coast: Ushant was the English name for Île d'Ouessant at the western tip of Bretagne. Woodcut from Robert Normans 1590 Safegarde of Saylers, a translation from a Dutch original (Taylor, 1956).

These coastal views were based on drawings made from the deck of the ship in that egocentric perspective we talk about. The idea was to be able to recognise the features of the coast just as it was seen from the ship and they can still be found in modern Pilot Handbooks.

The drawback of the coastal views was that they were only valid for one particular spot, the "Ft"-point in Figure 3. However, modern computer graphics technique makes it possible to produce dynamic coastal views by building a 3D topographic model based on digital terrain data and chart information. By positioning the virtual camera based on GPS position and heading an egocentric 3D map in real-time can be displayed.

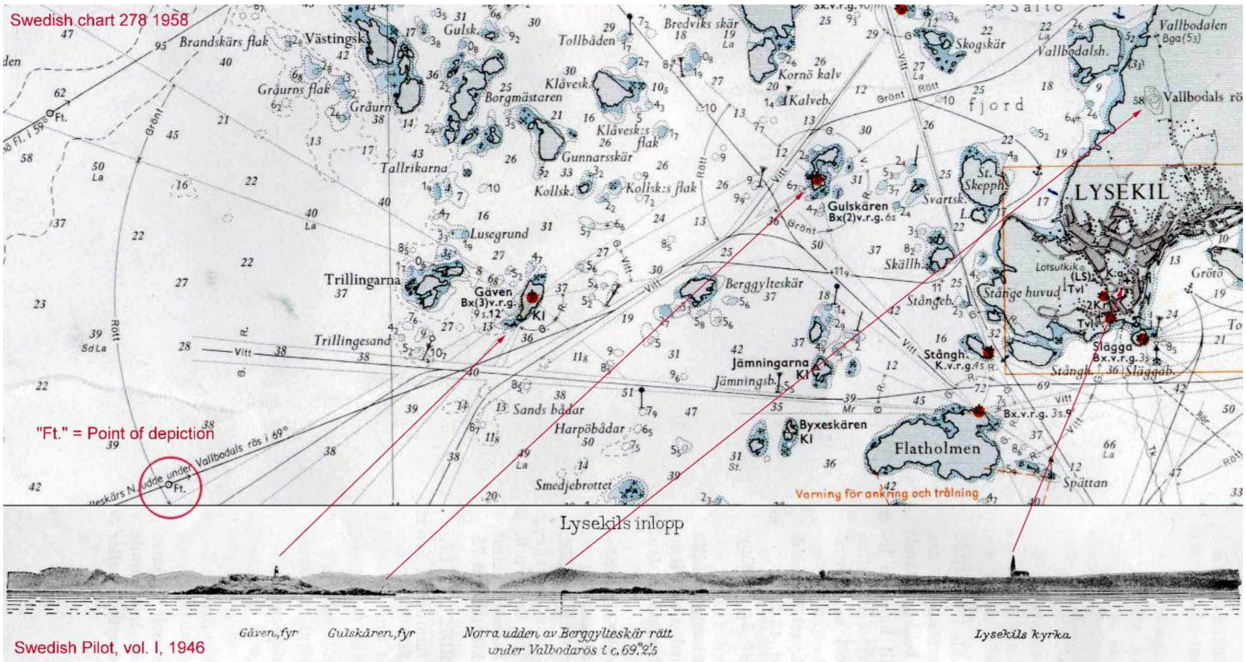


Figure 3: Top: a nautical chart from 1958 over the approach to Lysekil on the Swedish west coast. On the leading line at the bottom left of the chart the letters "Ft" ("Förtoning") is visible. This code tells you that there is a coastal view to be found in the pilot handbook of the area (the bottom part of the Figure). Ft is the point from which this egocentric view drawing is made.

The ide of the 3D model is to make a dynamic coastal view, a 3D nautical chart by positioning the virtual camera based on GPS position and heading. The picture from this virtual camera would be an egocentric 3D map.

The hypothesis presented above was tested in a maze experiment with the three different map types presented in Figure 1. The results are presented in detail elsewhere (Porathe, 2006; Prison & Porathe 2007), but the general conclusion confirmed the hypothesis that removing the need to make mental rotations improves decision making: head-up maps showed faster decision making and less errors than north-up oriented maps and egocentric 3D maps were better than head-up maps.

The basic features in a 3D nautical chart are presented in Figure 4.

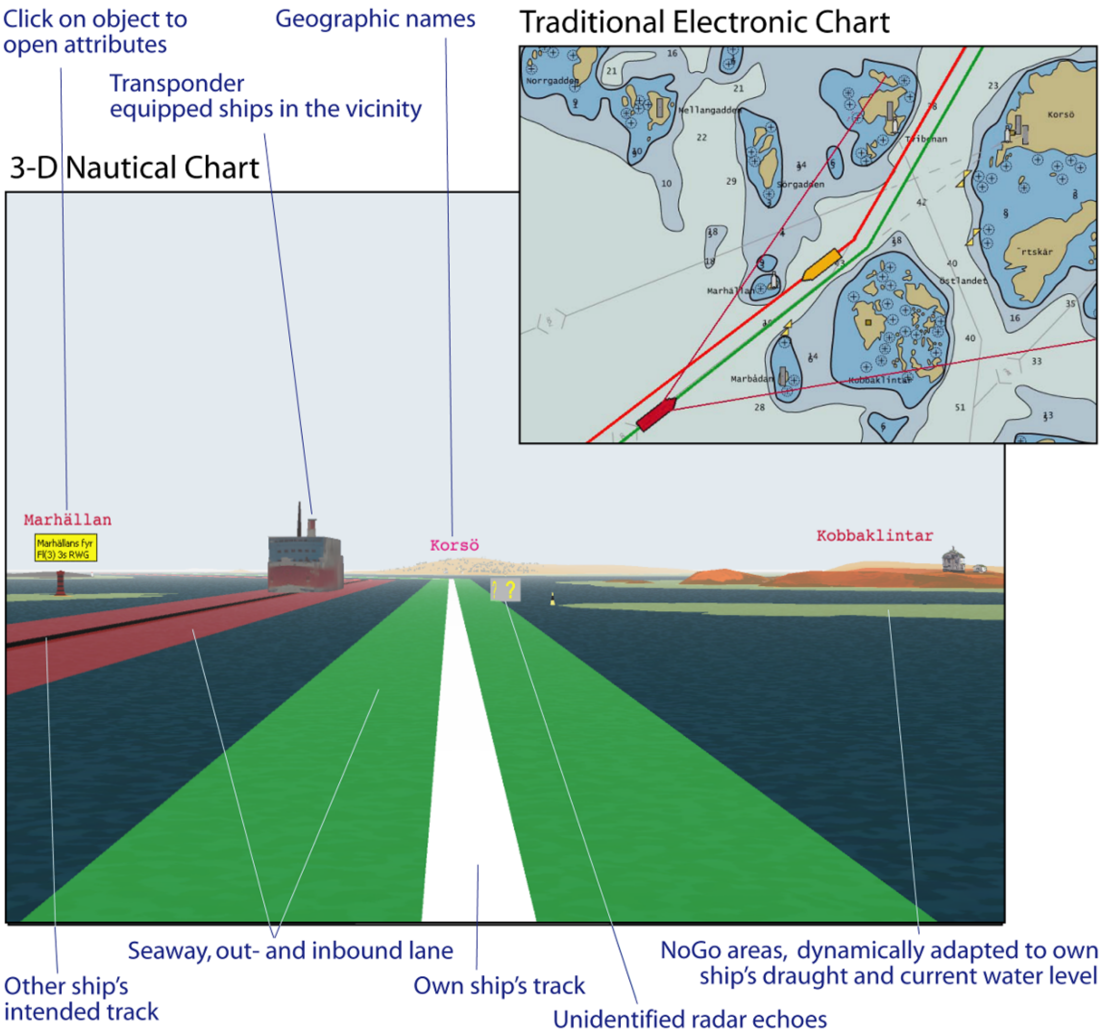


Figure 4. The egocentric view 3D chart to the left, compared with the traditional exocentric bird's-eye view chart top right (Porathe, 2006).

2. Data acquisition and modelling - Construction of the 3D model.

2.1. Selection of test area

The Selection of Zeebrugge (see Figure 5) as a test area was done in close cooperation with WP4 Partners from Belgium, Denmark, Norway and Sweden using a set of agreed selection criteria to ensure the widest consensus on the selected test area.

The agreed selection criteria were the availability of the following:

1. Detailed Bathymetry – Free of Charge
2. Detailed Imagery - Free of Charge
3. Simulator facility
4. Detailed Terrain Model - Free of Charge
5. Pilots / Navigators willing to participate in the evaluation
6. Lying in another WP area of interest
7. ENCs over Area of interest - Free of Charge

Partners from Belgium were able to provide all the necessary source data for the 3D model. Further, contacts through the partners from Belgium ensure the cooperation of the navigators operating in the port of Zeebrugge and with the staff from a simulator facility in the vicinity of Zeebrugge. Zeebrugge was also located in the test areas for WP3 and WP6, so Zeebrugge emerged quickly as the strongest candidate for a test area.

Source data for the test area were provided by the Belgium Hydrographic Office (BHO) and the Belgium National Land Survey (AGIV). The cooperation of AGIV was secured by BHO and free of charge for BLAST as AGIV is not a BLAST partner.

2.2. Constructing the 3D model

The area of interest for the 3D modelling is illustrated in Figure 5.

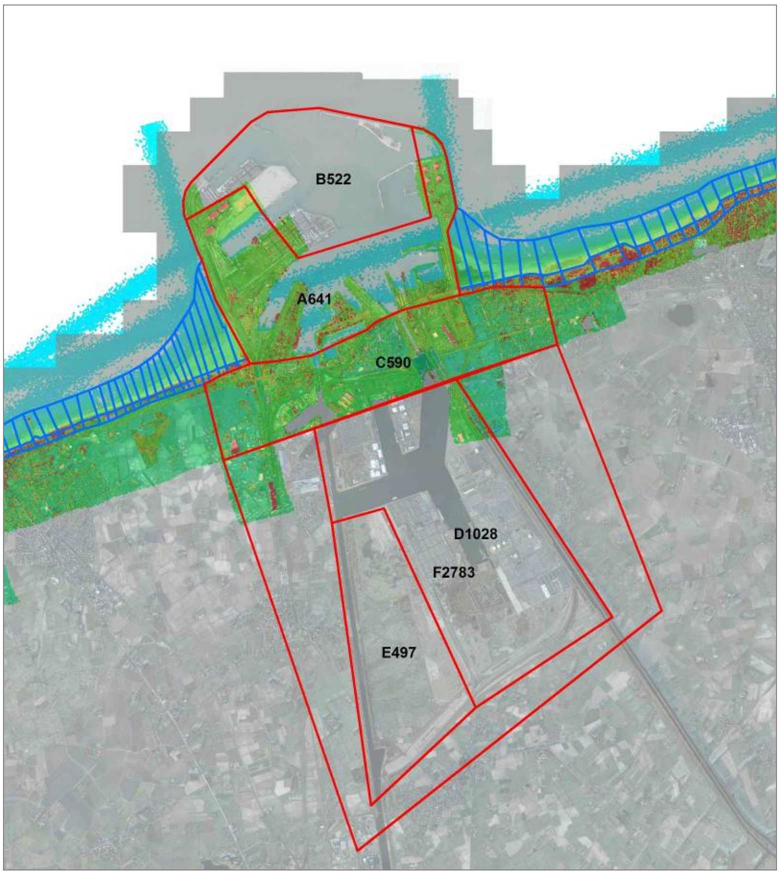


Figure 5. Aerea of Interest - The Port of Zeebrugge in Flanders.

2.2.1. Source data

Source data types received were:

- LIDAR data, 1 m resolution from 2009 and 2010 LIADA campaigns, Supplier: AGIV Belgium
- Orthophoto mosaic 40cm resolution, Supplier: AGIV Belgium
- Digital Terrain Model (DTM), 1 m resolution, Supplier: AGIV Belgium
- Bathymetry, 5m grid, ASCII format, Supplier: Flemish HO
- ENCs usage band “approach” and “harbour”, from Flemish HO

AGIV, the National Land Survey of Belgium, is not a BLAST partner. The Flemish HO secured the co-operation of AGIV and the delivery of the required source data at no cost to the BLAST project. The co-operation over the summer and autumn 2010 on test and evaluation of formats and resolutions of the data has been outstanding and the Flemish HO's work in securing the cooperation with AGIV has been commendable.

2.2.2. 3D model construction – the process

The production process consisted of several steps. The software used in the modelling process was RealSite modelling SW, which is developed by Harris corporation.

Production steps:

1. DTM integration (Bathy and terrain)
2. 3D building extraction, from LIDAR data
3. ENC feature selection and conversion to mode format
4. Integrate all data types DTM, 3D buildings, ENC features, Orthophotos, Digital photos to the final model.

The 3D modelling process started as per the schedule OCT 2010, with the bulk of the 3D building extraction work planned from mid NOV to mid DEC 2010. Unfortunately, a hardware breakdown late NOV caused the extraction work to stop. New hardware was acquired and through double shift and assistance from T-Kartor's partner – Harris Corporation USA - the planned delivery of the 3D model, ready for the navigational evaluation was made 06 APR 2011 in time for the evaluation trials.

2.2.3. 3D Viewer Acquisition

An EU tender process for the acquisition of a 3D viewer application for the use of 3D visualization in navigational aid displays was conducted over the 4th quarter of 2010.The tender contractor was contracted to deliver 16 licenses for the viewer application, one for each partner in BLAST. The licenses are valid until 30 SEP 2013 and were delivered during FEB to MAR 2011.

T-Kartor received two responses to the tender; one from IVS-3D, the well-known supplier of the Fledermaus SW, and one from Harris Corporation USA. The successful contractor was Harris Corporation offering the technically most compliant viewer as well as the lowest cost. The received bid was within budget.

The images in Figure 6 illustrates a part of Zeebrugge harbour together with a 3D view of the harbour as visualized in the 3D viewer.

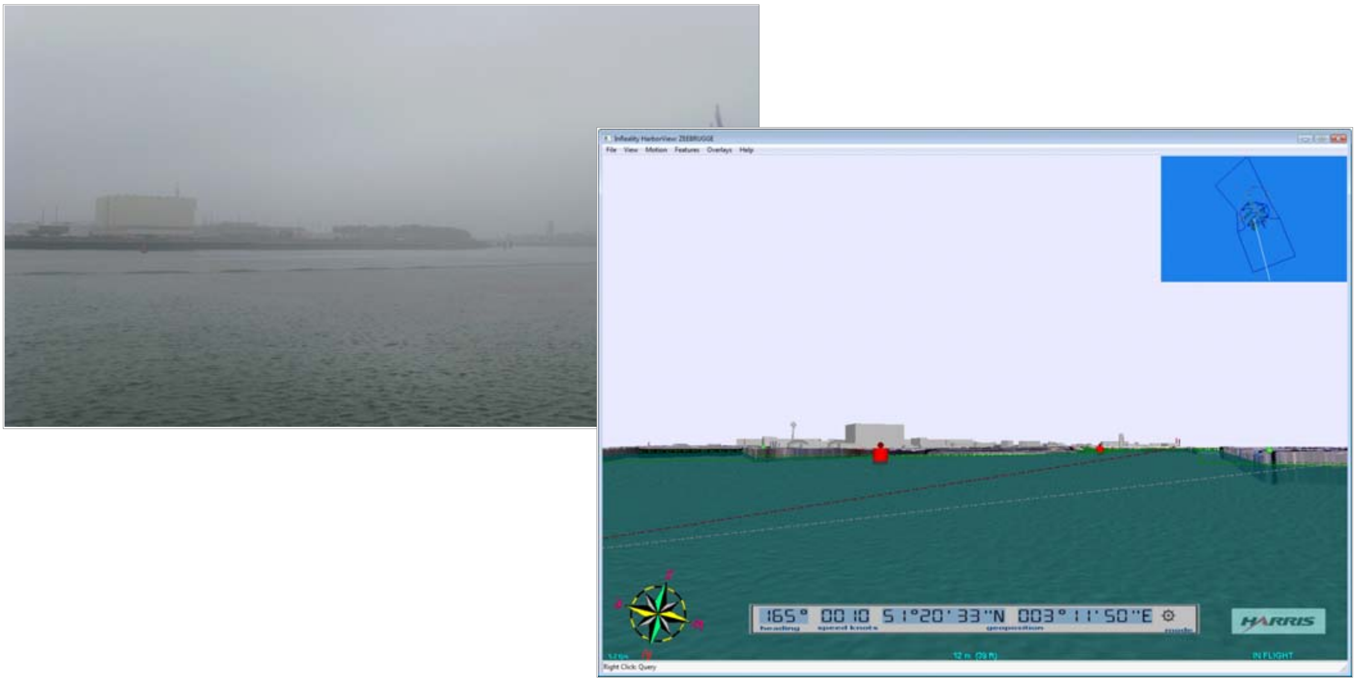


Figure 6. The Port of Zeebrugge in Flanders. 3D model right and real world, top left.

It is evident that the 3D view makes it easier to locate and identify navigational aids in reduced visibility. Note the Red buoy in front of the square building.
Further details on the usability of the 3D view is reported in the section “Evaluation of the 3D model below.

3. Evaluation of the 3D model

On April 27 and 28, 2011 a test of the 3D model was conducted using the simulator facility at the Maritime Academy (Hogere Zeevaartschool) in Antwerp and on the Flemish Hydrographical Office’s survey ship Ter Streep in the port of Zeebrugge. The objective of the evaluation was to test it in navigation and to collect user opinion from professional bridge officers.

3.1. Evaluation in simulator

At the Maritime Academy a professional Zeebrugge pilot took three large ships into port during extremely unfavourable conditions: very low visibility (about 300 m) and maximum NW going current, which just outside the pier heads of Zeebrugge can reach 4,3 knots. See the current map in Figure 7 generated from the simulator with the actual current settings used during the simulation.

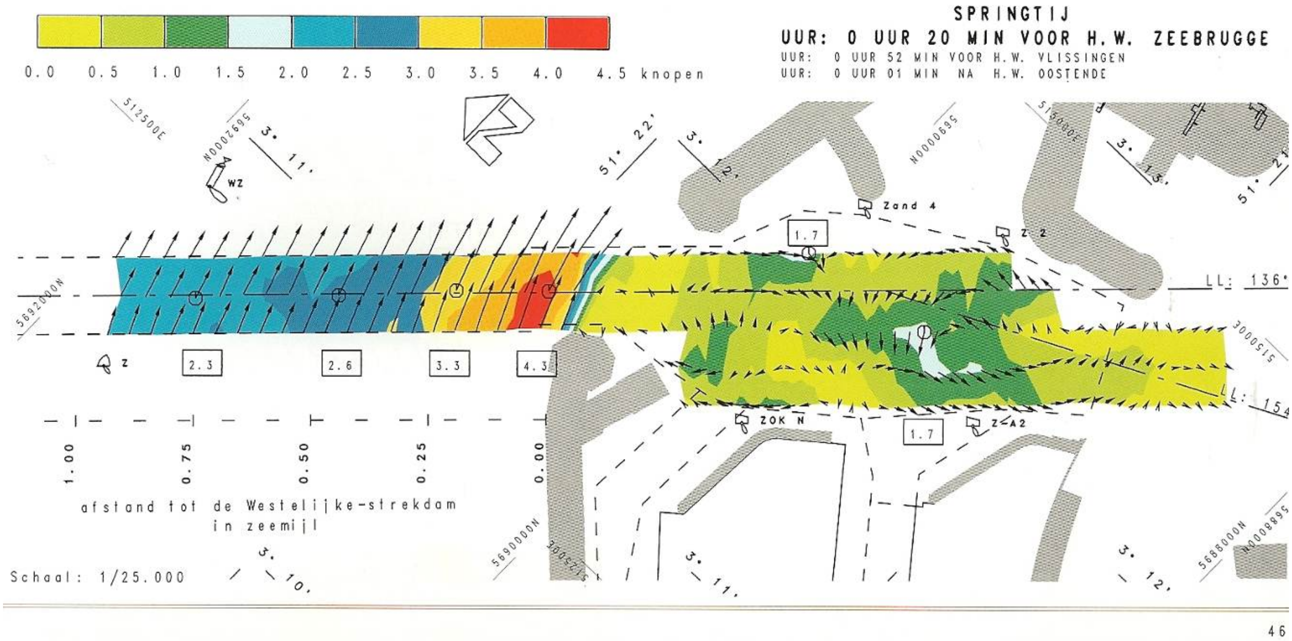


Figure 7. The current settings used in the simulation. To the left the approach channel to Zeebrugge and to the right inside the pier heads (grey areas). These settings were based on real tidal data 20 minutes after high water spring.

The three ships used were a 140 m long bulk carrier with a 9 m draught and a max speed of 13 knots, a 200 m long car carrier with a draught of 7.5 m and a max speed of 20 knots, and a 300 m long container ship (the maximum size that can enter the port) with a draught of 11 m and a max speed of 13 knots (see Figure 8),

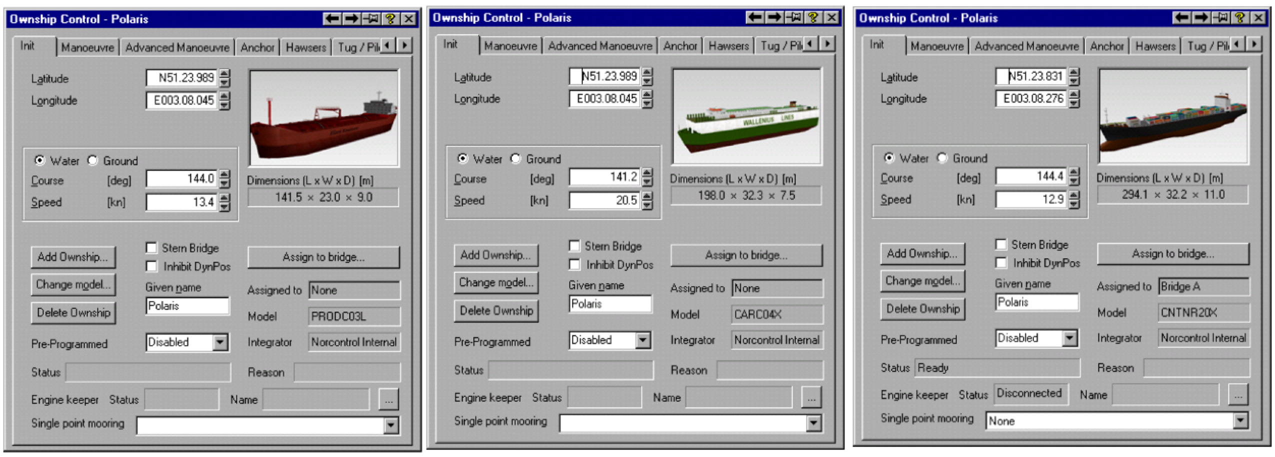
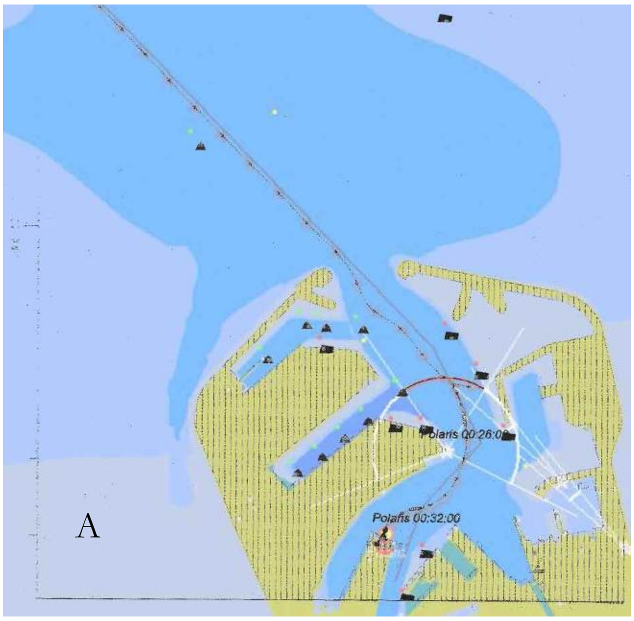
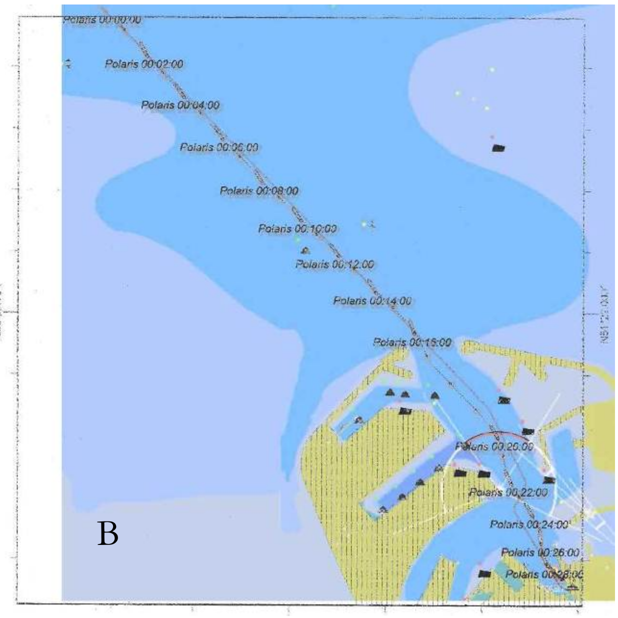


Figure 8. The three ships used during the simulator evaluation at the Maritime Academy in Antwerp.

The courses of the three ships are plotted in Figure 9: A is the bulk carrier, B the car carrier and C is the container ship. All ships had successful approaches but the container ship ran on land once inside the piers due to the absence of tugboats which were necessary to stop her (she had to keep a good speed to overcome the current outside the port).





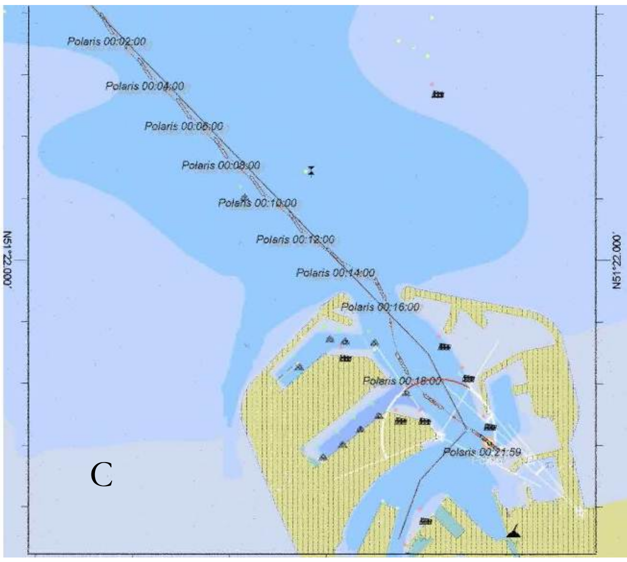


Figure 9. The course plots generated by the simulator after the three test runs with the three ships depicted in Figure 8.

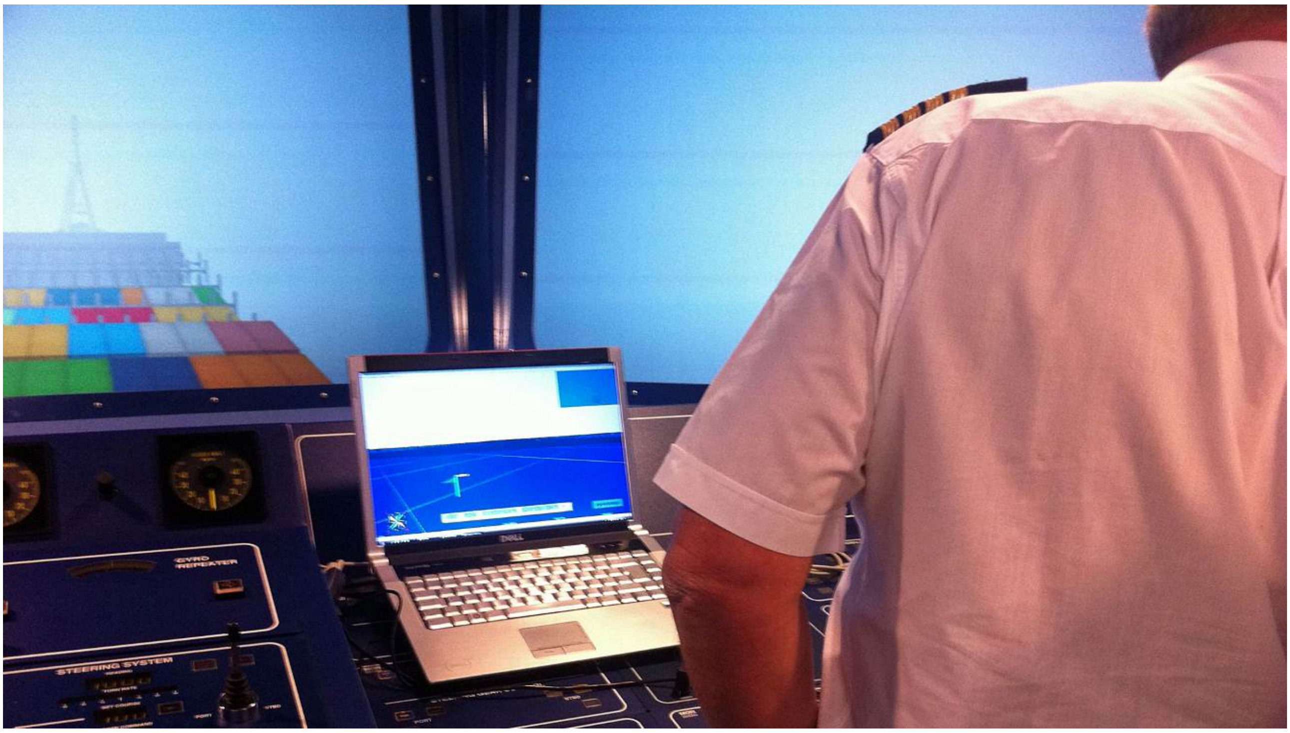


Figure 10. The 3D model installed on the simulator bridge as the 300 m long container ship, here in the entrance channel of Zeebrugge. Visibility < 300 m.

"We still need a birds view. In this [3D model] it is difficult to see the distance"

To conn the ship into port the pilot kept the bow up to 11 degrees up against the east going current. He used the electronic chart system (ECDIS) for this (see Figure 11, left). In ECDIS he had both a heading and a course over ground (COG) arrow visualizing heading and course over ground. In the 3D model only COG was visualized, and this had to be inferred by the motion of the ship symbol (a green flag) along the leading line into port. "It is fine with the leading line and the flag. But I need to know the heading. And I need to know where on the ship the green flag is. The ship is huge. Is the flag in the center of gravity? Or is it on the bridge? Or is it where the GPS antenna is positioned? I need to know that."

The crucial point for the pilot is when to turn port to anticipate the sudden absence of current once the bow passes the pier heads. By experience the pilot knows this distance judged on the speed of the current and the size and maneuverability of the ship. For the first bulk carrier this distance was judged to 2 cables (0.2 nautical miles = 370 m). With no visibility this distance was measured on the radar (see Figure 11, right). The lookout on the bridge was set to observe the radar and tell when the distance to the pier heads was 2 cables. The pilot commented on the 3D display: “We still need a birds view. In this [3D model] it is difficult to see the distance”

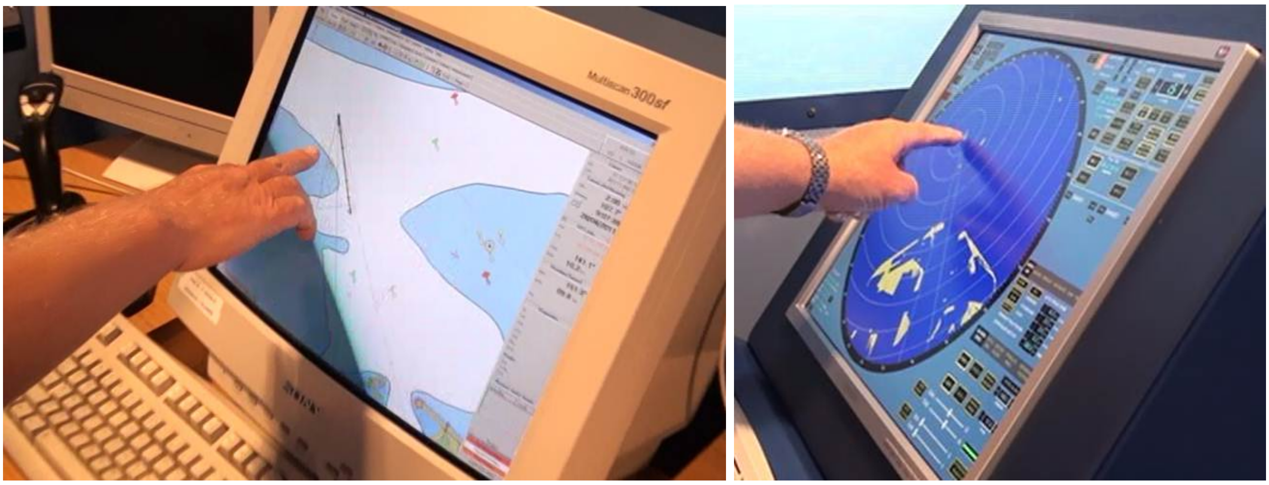


Figure 11. Left: The electronic chart system (ECDIS). Zeebrugge pier head in lower right on the screen. The thick line is the course over ground (COG) and the faint line 10 degrees more clockwise is the heading. Right: the radar display with the concentric range circles. Here every circle represents one cable (0.1 nautical miles). Pier heads in the lower part of the screen.

Figure 12. The pilot used the 3D model to monitor that the ship was on the leading line into the port.

None of the above measuring methods; distance and heading, was supported in the 3D model. The ship was represented by a flag that followed course over ground. So the pilot used the 3D model to monitor that he was on the leading line into the harbor (see Figure 12).

Results from the simulator test was that the 3D model was beneficial for monitoring course over ground, and the pilot also used it for this during the test runs. However it did not in its present form support navigation by allowing the pilot to monitor heading and to make measurements. In fact the foreshortening effect, which is an inherent consequence of the egocentric perspective, made it more difficult to judge distance to objects, which was commented by the pilot with “You still need the birds-eye view.”

3.2. Evaluation at sea

The sea trial was conducted onboard the Flemish Hydrographic Office’s survey ship *Ter Streep* (see Figure 13). We left the port of Oostende on Thursday morning the 28

April 2011. There was a fresh NNE wind 6-7 Beaufort which produces quite some swells from the North Sea which gave several of the research team a chance to feel seasick. After about an hour we reached the starting position at the Zulu buoy outside the port of Zeebrugge. The tide at the Z buoy 11:30 was HW, +3.5 m with an east going current of 2.5 knots. The visibility was limited to 2-3 miles with a light rain off and on.

Figure 13. Top right: The survey ship Ter Streep. Left: The 3D display to the right of the helmsman on the bridge.

The first comment from the captain at Ter Streep was “Why is that not a ship” pointing at the green flag representing the own ships position in the 3D model (compare the comment from the pilot in the simulator). Other software bugs like the fact that the green flag with its passed track representation submerged under the water surface in the 3D model and became invisible, and that the heading value displayed on screen actually was those of the camera and not the heading of the ship caused some confusion from time to time.

Because the visibility was much better, the current weaker and Ter Streep a smaller and more maneuverable ship, the navigation problems found in the simulator was less obvious during the sea trial. The impression judged by the captain was that the positioning of the target was very accurate and the 3D display was used to check that Ter Streep was on the leading lines as she sailed into the inner harbor, made an approach to the van Dame locks and then out of the harbor again. Comments by the captain were that the hull contours of the ship had to be displayed and some way of measuring the distance to things was needed. But also that “this is going to be fine when it is finished.”

During the observation it was obvious that the helmsman used the ECDIS display most of the time and only occasionally the 3D model.

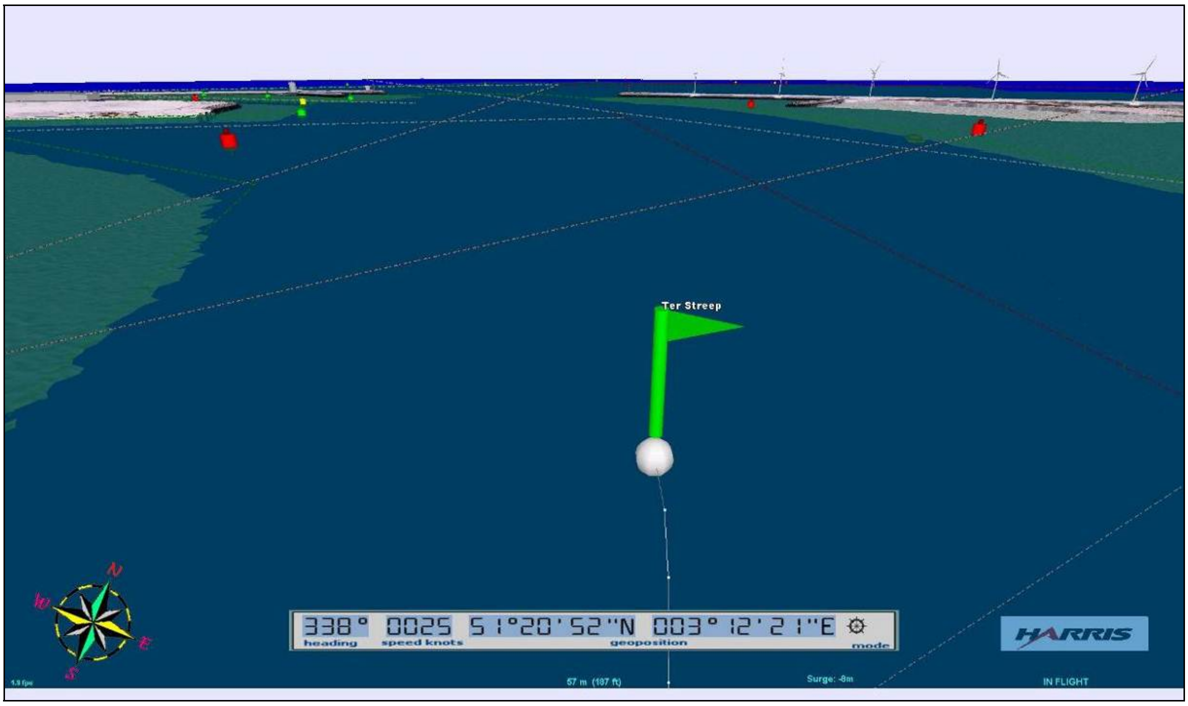


Figure 14. Ter Streep on the way out of the harbour. Pier heads ahead. The green flag representing the position of the GPS antenna on-board. Note that the heading value (the first number in the box in the lower part of the screen) is the direction the “camera” is pointing at, not the heading or COG of the ship.

3.3. Comments on the model

Several good features of the 3D model were commented on and used in the simulations. The oversized buoys allowed them to be seen and identified on long distances (see Figure 15). Also the leading lines placed on the water surface working like lanes (but they were somewhat difficult to see and should have been more visible – see Figure 16).

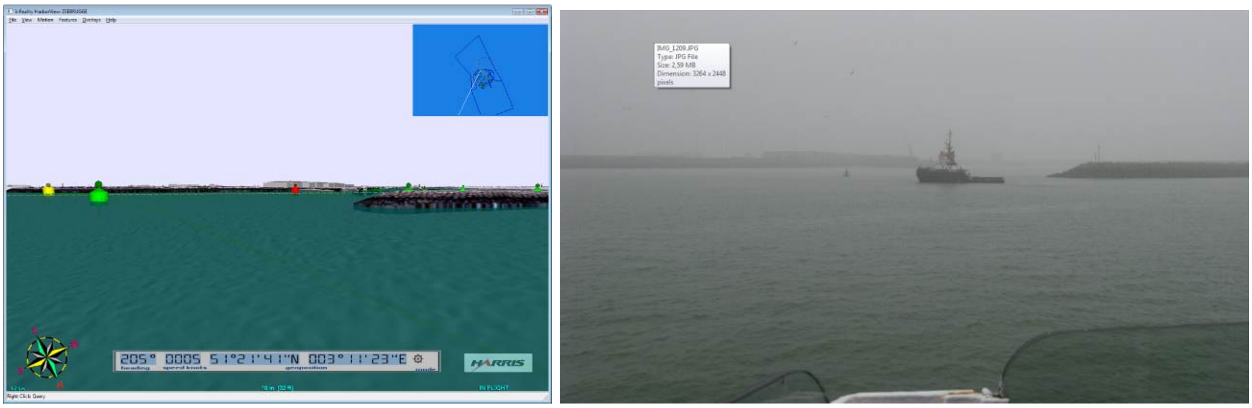


Figure 15. The oversized buoys in the 3D model made them much more visible that in real life.

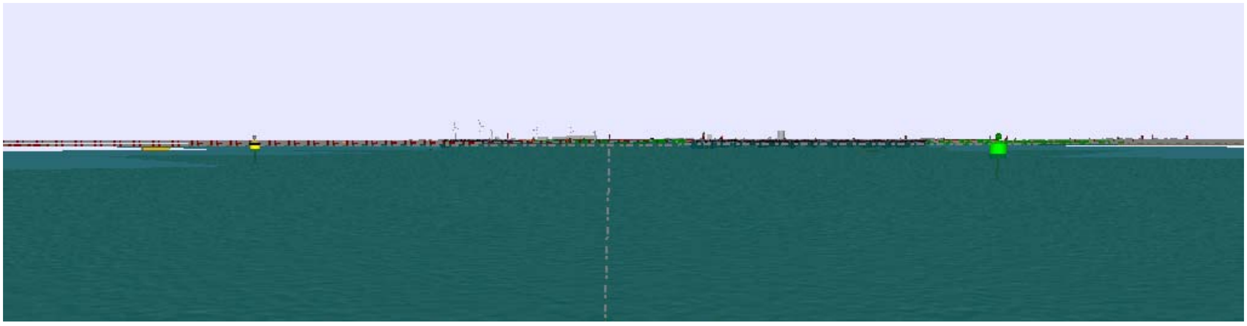


Figure 16. The course into port represented by a leading line. This line needs to be more visible and also separated into an ingoing and an outgoing lane.

3.3.1. Issues found

There were some issues that became clear during the evaluation. One of these issues had to do with the detailing level of the 3D model constructed in the project, but most issues derived from the software platform that displayed the model and this platform was not open to changes.

Issues with the 3D model

Visual iconicity is the term used for good resemblance between the model and the real world. Ideally a subject well-known in the area should be able immediately recognise where he or she is. This has to do with the level of details in the model, but also which details are modelled. For instance, landmarks like windmills, oil tanks, lighthouses and cranes will have to be there to give the close resemblance needed for good visual iconicity. In some parts of the visual iconicity were just right, see examples in Figures 17 and 18.

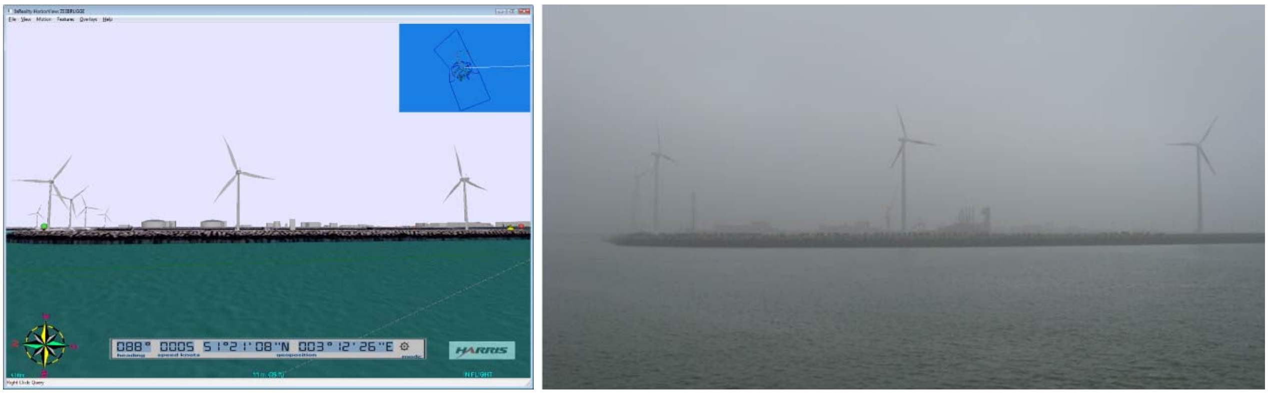


Figure 17. The windmills on the breakwater was an obvious landmark. The representation of them in the model lead to good visual iconicity in that part of the model.

Figure 18. The oil thanks of the inner harbour was another land mark well represented in the 3D model.

In other parts of the model well-known landmarks were missing or modeled in a simplified way that did not support recognition. Examples are the harbor cranes and some conscious lights and towers (see Figures 19 and 20).

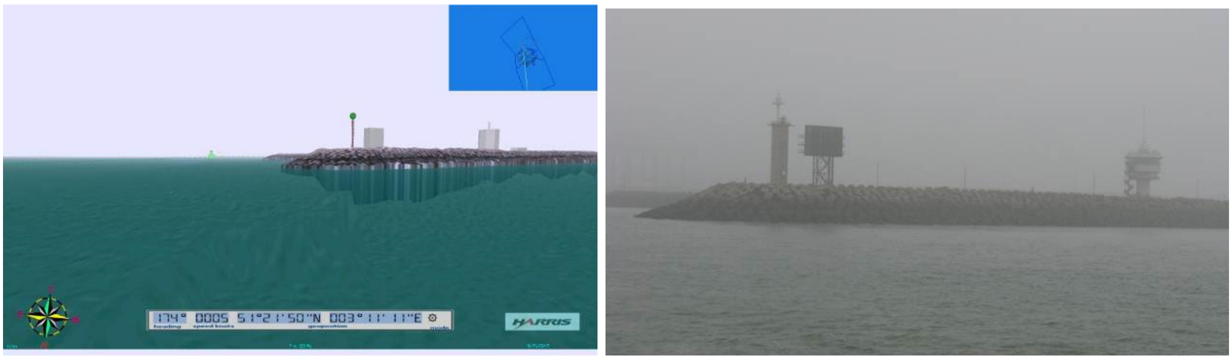


Figure 19. The Light, signalling board and watch tower of the SW pier are well known landmarks by entering Zeebrugge. They were less well represented in the model.

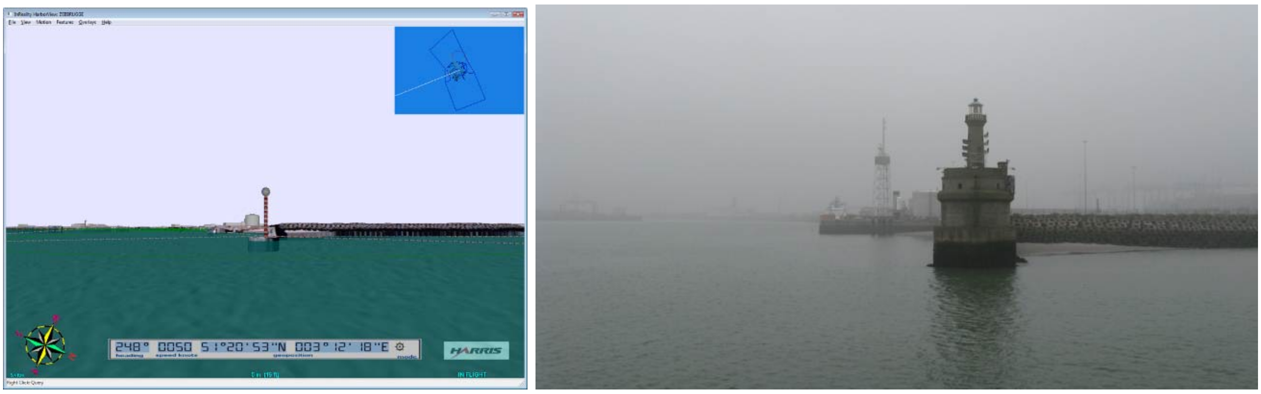


Figure 20. The inner loighthouse is a well known landmark too simplified in the model. The conspicuous radar tower of the port control was not represented at all.

Issues with the software platform

The Harris' HarborView™ platform allowed presentation of geographical data with high precision. Real-time input from the GPS positioned the target ship in the application and also the camera following the ship. However when the GPS was plugged in and HarborView set in "live feed" and the camera on "follow target" the resulting picture was too tight and too angled to make any vision ahead of track possible (see Figure 21). And these settings were not adjustable. Instead we had to connect only the target (the green flag) to the GPS feed and the camera had to be manoeuvred manually by using the arrow keys on the computer keyboard. In the simulator trial in Antwerp this was done by the captain (who sometimes forgot it and let the target slip away into the distance) and on the survey ship it was done by a member of the research team.

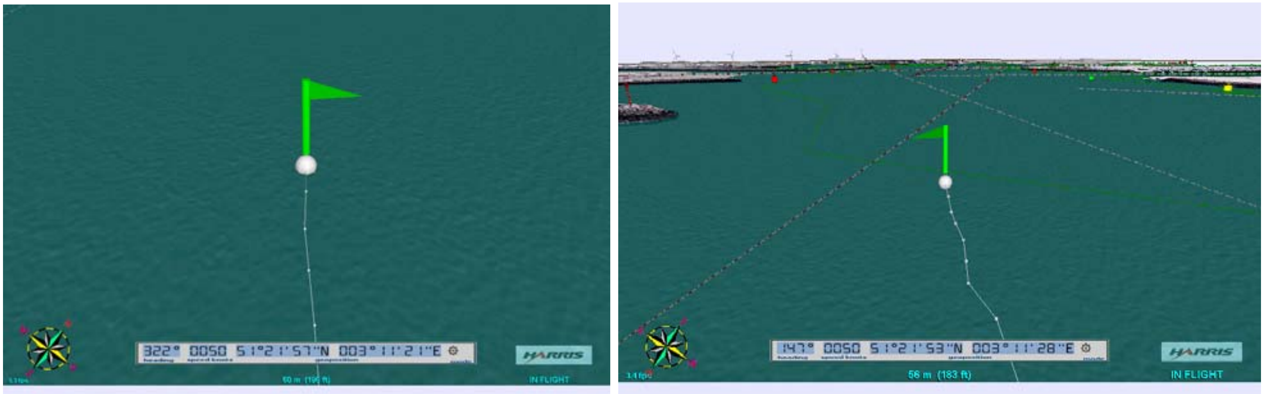


Figure 21. In the “follow target” mode (left) the vision ahead was very limited. To be of any use the camera had to be manoeuvred manually to allow an optimized view (right).

HarborView could also not receive high speed data over the ships pilot plug but an older portable GPS receiver had to be used with an update frequency of sometimes several seconds.

It was not possible to reconfigure HabourView and to change the representation of the target (the flag) although different colours could be chosen. But what the participants wanted was to have the contours of the ship and also the heading line. The course over ground was in some respects visualized by the past track markers. And there was several problems with keeping the flag stable on the water surface.

3.4. Conclusions

Radar and the traditional electronic chart system with its exocentric bird’s-eye view will in times to come remain the major strategic and voyage planning tool. The evaluation shows that the 3D chart in its present design cannot work as a standalone navigation tool. But this has never been the intention. The 3D nautical chart is intended as a tactical display, being a last barrier to navigational errors due to loss of situational awareness in stressed situations. Experimental and practical results are so far is promising, but much research still needs to be done.

4. Automatic change detection

A change detection analysis has been conducted comparing the 3D model with the harbour scale Electronic Navigational Chart (ENC) over Zeebrugge.

4.1.1. The change detection process

- 3D feature objects extracted in the production process are separated integrated model for change detection.
- 3D features are collapsed to 2D and their interior geometry is dissolved leaving perimeter feature boundary polygons
- The collapsed/dissolved features are conflated using ArcGIS scripts which “reference” 2D feature polygons extracted from the harbour scale ENC
- Based on conflation results, features are segregated into 3 groups
- ADD – New features which do not correspond to reference
- MOD* – New features which correspond to reference
- DELETE – Reference which do not correspond to new features

The results of the change detection in form of a differencing plot, corresponding GIS readable files and a process description were delivered to BLAST partners.

The illustration in Figure 22 shows the detected changes in an overview and zoomed to illustrate the detail.

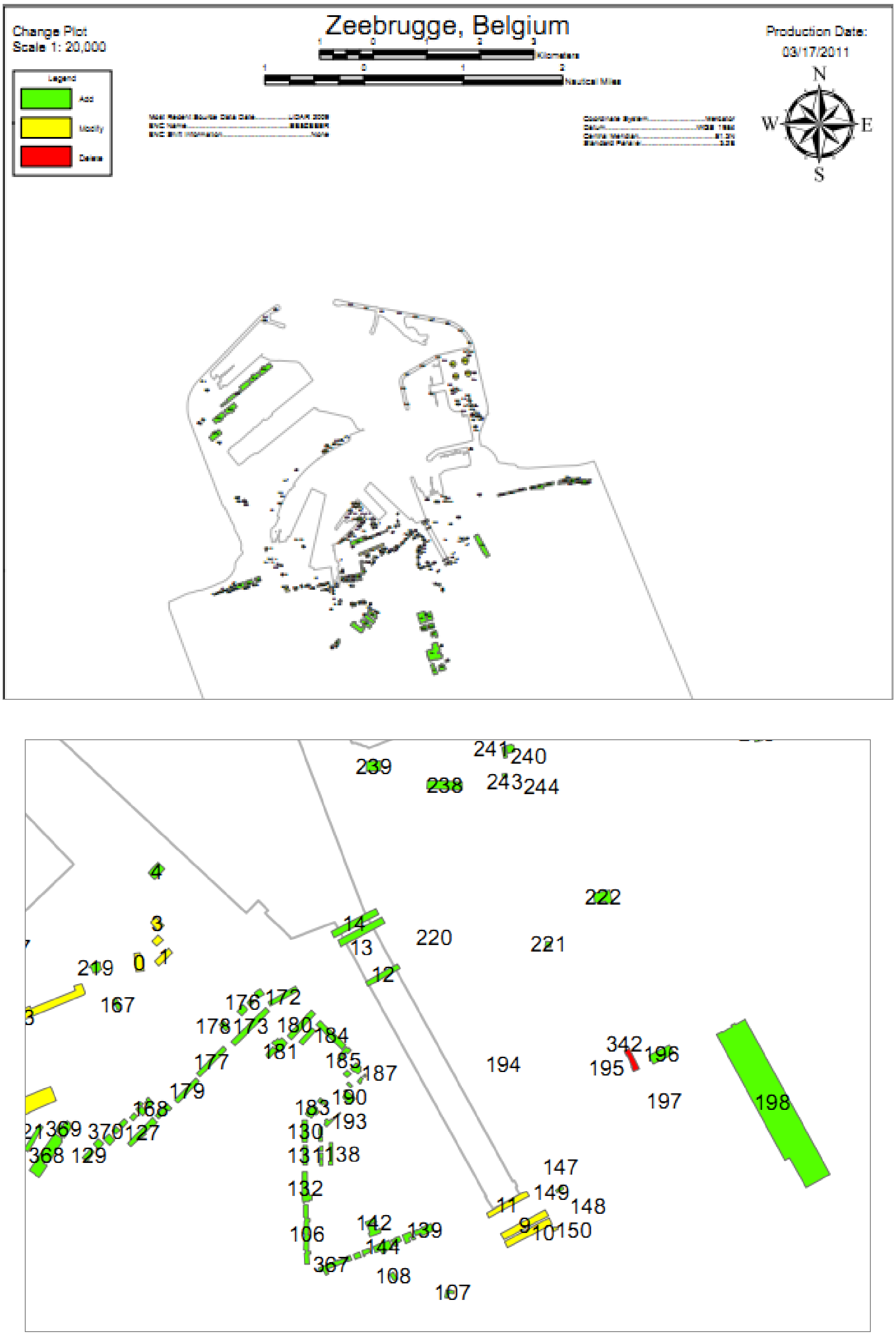


Figure 22. The detected changes in an overview (top) and zoomed (bottom).

Identified changes can be readily used as the basis for updating the infrastructure information in the map and chart products available over Zeebrugge Harbour.

The GIS readable files include the detail geometries, correctly georeferenced and easily imported into most hydrographic production tools.

A total of 375 changes / differences were identified in the demonstration.

The illustration in Figure 23 below shows the change data visualized in Open Source GIS QuantumGIS.

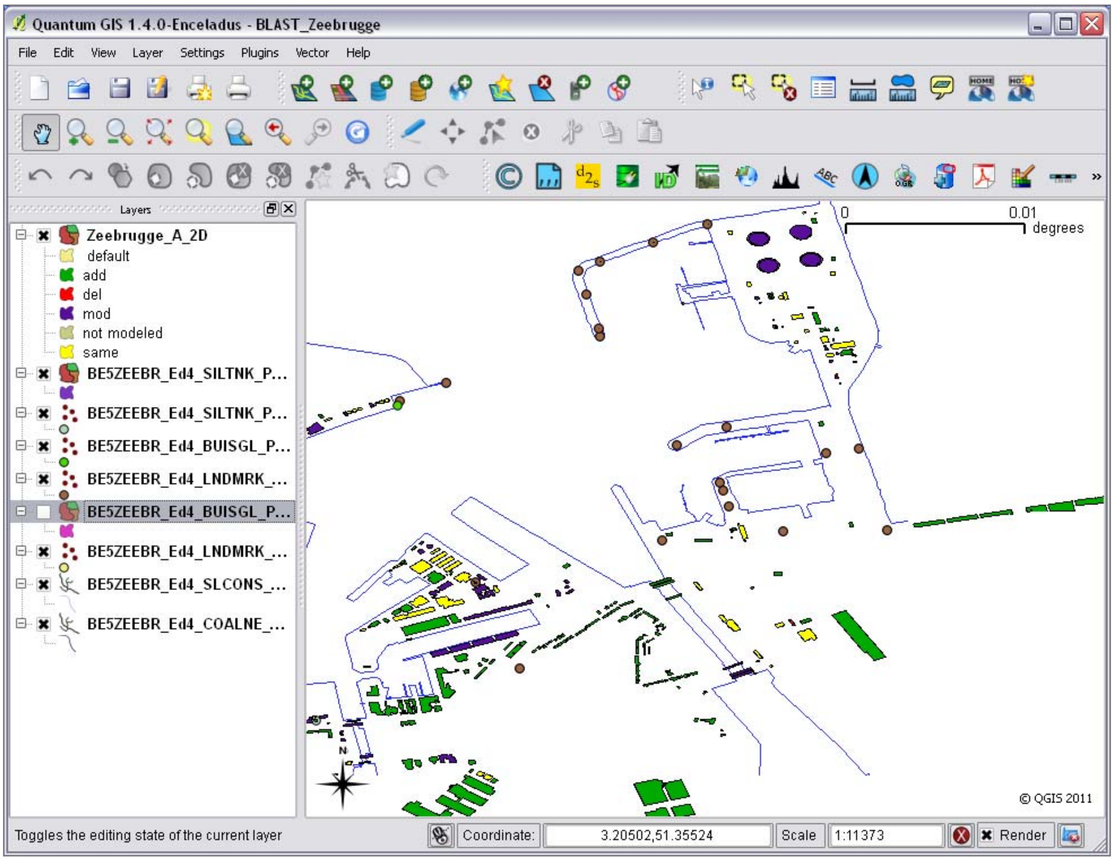


Figure 23. The change data visualized in Open Source GIS QuantumGIS.

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