SandBox-FM: Augmented reality CFD

Hydraulic engineering and education through collaborative modeling

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Abstract

The SandBox-FM is an innovative collaborative modeling tool. It offers the possibility for various stakeholders to interact with a real time hydrodynamic computation by adjusting the model geometry in the sand. The impact on the hydrodynamics are visualized instantly, which contributes to system understanding, enhances communication between stakeholders and ultimately could affect the decision making process. This extended abstract presents the design, lessons learned and an outlook of future plans of the SandBox-FM.

Introduction

The advance of computational power since the 1980's has led to great technological developments. In hydraulic engineering, it is currently possible to predict hydro- and morphodynamics for decades using advanced computational models. Such models have proven to be very useful during the design phase of hydraulic measures. However, the use of complex computational models also shows limitations during the design process, particularly when part of a multidisciplinary decision making process with many stakeholders from various backgrounds. The limitations can be identified as follows:

- A computational model requires an expert modeler, this might limit the possibility of stakeholder input.
- The complexity in the model setup limits the number of iterations in design processes.
- Many stakeholders are not familiar with computational models and unable to interpret the model results correctly.
- Models lack interactivity.
- The building of models has a steep learning curve for new users, like students.

The objective of the current research is to develop a participatory tool which allows stakeholders to interactively design hydraulic measures. The tool should therefore (1) create a lower threshold to engage with models; (2) calculate designed measures in a shorter period of time; and (3) present results in a manner which is easier to understand by all stakeholders. Ultimately, the tool should contribute to establishing more accepted designs or a shorter design process and it should reduce the learning curve for students so that they can focus on the research they set out to do.
To that end, we developed the hybrid physical-numerical model, named "SandBox-FM", as a tangible user interface combined with either a Delft3D-Flexible Mesh (FM) or an XBeach model. In this extended abstract, we focus on the design, lessons learned, current limitations and share an outlook of future plans.

Background and related work

Similar to computational power, computer interaction has evolved drastically in the last decades. One recognized way to facilitate easy, intuitive and low-threshold interaction with digital information such as models is through tangible user interfaces. The main principle behind such interfaces is to provide physical forms to digital information. These physical forms serve as both control and representations for their digital counterpart. This way, tangible user interfaces make use of people's ability to grab, move and change physical objects or materials.

Recently, some attempts have been made to increase the interactivity of hydraulic models using tangible user interfaces in the scientific community. For example, Donchyts et al. (2014) developed a system to model the interaction of saline and freshwater using the Delft3D-FM model (Kernkamp et al. 2011) in combination with Leap Frog's Leap controller. Reed et al. (2016) developed the LakeViz3D, which allowed users to interact with the geometry in a physical sandbox. Using a Kinect to detect depth, the bed level was subsequently displayed by a beamer projection onto the same sandbox.

Our approach

In the current study, the LakeViz3D approach was extended by coupling the measured depth to a Delft3D-FM model to simulate overland flow. The current SandBox-FM consists of a 1 by 0.8 m frame with a height of roughly 0.1 m. The frame is filled with a geometry built from sand that can be shaped by users. Optionally, a 3D-printed scale model made can be included to model a reference situation. The setup was made easily transportable to fit in a single suitcase (Figure 1). A Kinect is used to obtain the depth information, which is subsequently transferred to the simulation. The simulation updates, and a user's choice of results (e.g water level, flow magnitude) from the simulation are projected back onto the sand through the beamer. To further understand the flow patterns, particles or an image can be added to the visualization, which is subsequently transformed by the flow. The Kinect, beamer and Delft3D-FM simulation are connected using a python interface running on a single laptop.

Results

The SandBox-FM offers an innovative way of visualizing hydrodynamic results, which is no longer static, but 2.5D, real-time and interactive. Changes in the bed level are imposed in the Delft3D-FM in a few seconds after pressing the update key and the flow field immediately starts adapting to the new situation. The Sandbox-FM has a refresh rate of 4-6 Hz which is relatively low, but due to the 2.5D visualization this does not seem to hamper the understanding of the underlying processes or the user experience.
Currently there are four different working examples for the SandBox-FM:

- The Barrier island case, which demonstrates the flow over and around a barrier island based of the coast of Portugal. Unique to this case is the coupling with the XBeach flow engine rather than the Delft3D-FM simulation (Figure 2).
- The Sand Engine case, which shows the impact of various shapes of nourishments on hydrodynamics (inspired by large nourishment constructed off the Dutch coast near Ter Heijde, Figure 3).
- The Ameland case, which shows the tidal dynamics of the tidal inlet between the Dutch barrier islands Terschelling and Ameland. This case has been successfully used for stakeholder session to discuss the impact of possible future nourishments on hydrodynamical processes (Figure 4).
- The Dutch River Waal case, which shows the hydraulic effect of measures in the River Waal (Figure 5).

The SandBox-FM has been used in numerous workshops and been presented at various conferences. The overall impression is that the SandBox-FM is well received by the general public and researchers alike. Especially for those without an hydraulic background, the SandBox-FM provided them with an easily understandable, accessible and interactive model. Experiences so far revealed the fun fact that young people seemed intrigued to experiment (for instance closing off the entire river), whereas people above 35 seemed more reluctant to engage with the SandBox-FM at first but started experimenting later on.

Limitations and future work

In this section we discuss some of the limitations of the current approach and an outlook of future plans.

Currently, scaling of features such that the vertical dimension is exaggerated is necessary as the Kinect camera can only resolve features larger than 2.8 mm in the vertical direction at the 1 by 0.8 m scale at which we are now working (according to UC Davis). This implies that the SandBox works best when well defined features are created. We aim to investigate how to increase the spatial size of the box such that larger scale models are also possible.

A manual intervention is currently required to update the bed. The interactivity and user experience could be enhanced if this process is automated. In addition, adding more attributes such as weirs, gates and pumps could allow for a better representation of the features which are present in reality.

As mentioned in the previous section, the refresh rate is rather low and this could be improved. This seems to be caused by the python visualization package used, which is easy to adapt for new applications. The refresh rate could be improved by switching the visualization package or by decoupling the computation and visualization steps (only requesting a new flow field from the model when the visualization is ready to process it).

The application is currently limited to a single pc computation. In the future we would like to speed up the model or refine the computation. This would require multiple processing units, running the model in the cloud and transferring back the alterations to the laptop to subsequently visualize the results.

Water levels are difficult to compare in the visualizations. Adding a second screen, in which water levels per scenario can be compared at an observation point, could add to the user experience. Another possibility would be to combine the SandBox-FM with a virtual or an augmented reality environment.

We would also like to further investigate and quantify the impact of the SandBox-FM on social, collaborative and participatory modeling.

Conclusion

The SandBox-FM can be used as an educational tool and as a tool for stakeholder discussions on the hydrodynamic impacts of changes caused by hydraulic structures and spatial interventions. The goals of the project have been partly achieved and there are many ideas to extend and improve the current project. Moreover, the SandBox-FM is well received by the general public and researchers alike. We would like to acknowledge the contribution of the LakeViz3D project that made the initial setup of the SandBox and who open sourced all the details to their setup and software. To follow in good fashion our approach is also available as an open source project as well. Furthermore, we would like to thank Jan-Willem van Velzen, Jos Ooms, Gerben Hagenaar and Jesse Metz for their contributions to the project.

References

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Figure Captions

Figure 1: Sandbox-FM setup illustrating the connection between the different components

Figure 2: Sandbox-FM for the Barrier Island case (during RISC-KIT final conference, April 2017)

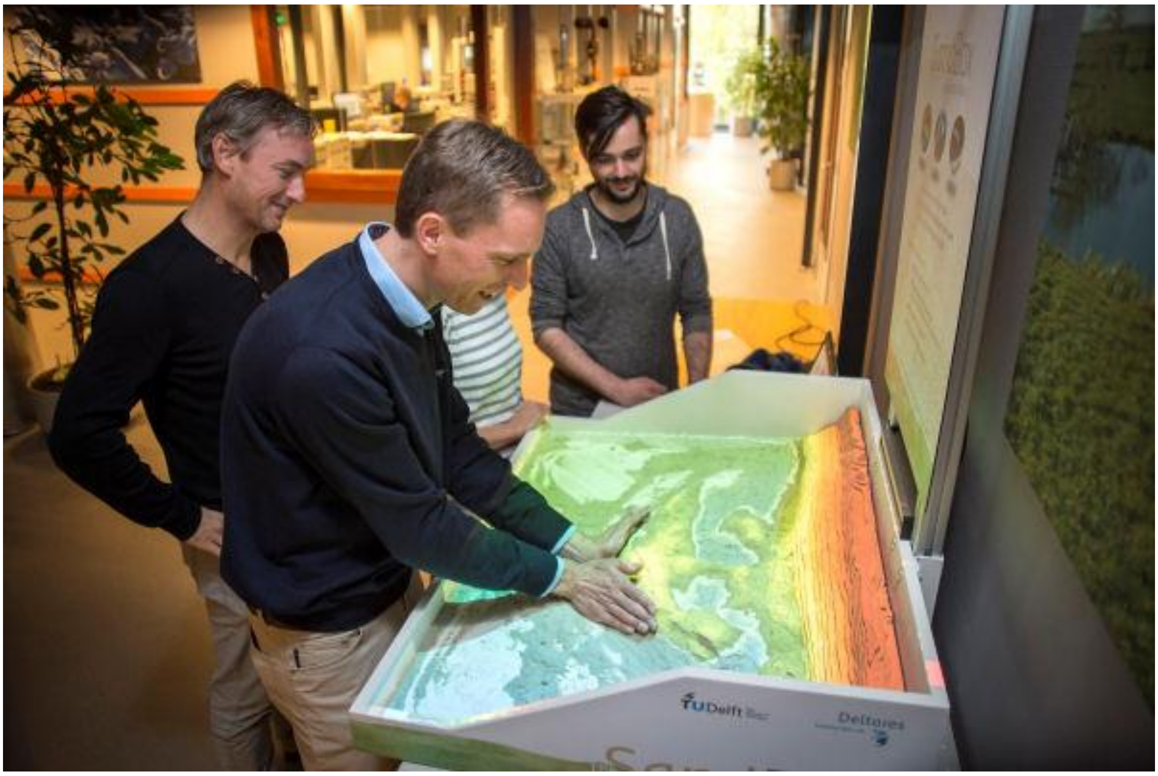

Figure 3: Sandbox-FM example for the Sand Engine case

Figure 4: Sandbox-FM for the Ameland tidal inlet case (at a stakeholder session with local community on Ameland, February 2017)

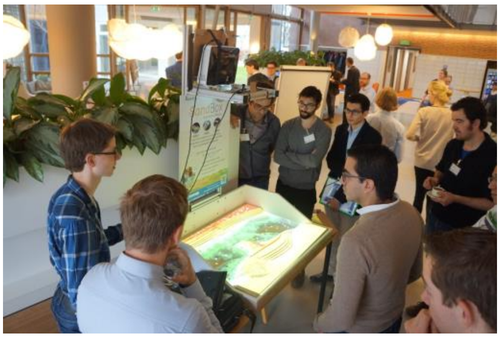

Figure 5: Sandbox-FM for the Dutch River Waal (during NCR days 2017 at Wageningen)

Author biographies

Dr. Willem Ottevanger is a researcher/advisor of large scale river hydrodynamics and morphodynamics with a background in applied mathematics and civil engineering. He is an experienced developer of computational river dynamics software and uses data analysis techniques for pre- and post-processing measurement and simulation data to generate models and visualizations to explain river processes and effects of measures. (willem.ottevanger@deltares.nl)

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Dr. Fedor Baart is an expert in the field of integrated modeling. His goal is to make computer models data driven, interactive, visually attractive and exploratory. In his work he combines his unique academic background in technological and behavioural sciences, with his outstanding knowledge in information sciences and database technology. In his role as software architect and developer at Deltares, he plays a key role at Deltares in the development of information systems and user interfaces based on the latest technology. (fedor.baart@deltares.nl)

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Cindy van de Vries MSc is a researcher/advisor working on software development at Deltares. She focuses on visualizing data sources in an interactive environment using state-of-the-art technology. Combining her software development skills with her Hydraulic Engineering background, she is a valuable asset to the company. (cindy.vandevries@deltares.nl)

Arjen Luijendijk is a coastal researcher and advisor focusing on coastal morphodynamics related to engineering interventions. He is a PhD candidate at the Delft University of Technology where he investigates the behaviour of the large-scale nourishment pilot called the Sand Engine through integrating state-of-the-art numerical models. He is a postdoc researcher within the STW program NatureCoast where a group of 12 PhD researchers from seven different disciplines all collaborate on the understanding the behaviour of the Sand Engine. He is a specialist in numerical modelling of coastal morphology on sandy and muddy environments. (arjen.luijendijk@deltares.nl)