Answers to the comments

Wednesday 8th December 2021

Dear Editor, dear Katherine

On behalf of the authors of this paper, I want to thank you for your additional review and detailed comments. We have addressed your comments in the revision of the paper. These are highlighted in the submitted PDF and detailed below, referring to your comments included in italic font.

1. *Overview*
   Generally, this paper is improved, but it still needs some further improvements before publication. Overall, what is the point of the work? It is a huge effort to bring dynamic analysis inside of a conceptual design optimization process. Would an approach using static analysis be able to capture the effects on constraints and allow for similar exploration of the design space without the heavy computation? The key for showing this paper is value is that including the in situ dynamic analysis adds realism that a static analysis would lack and thus drives the designs differently.

   Since "static analysis" in terms of using ultimate loads only does not comply with all the current literature, where at least a frequency approach is needed to capture the oscillatory load, "static analysis" is understood rather as a "quasi-static" frequency approach. With this understanding the following additions are made, pointing out the benefits of applying such a time-domain analysis instead of a frequency-domain one, e.g., inclusion of transient loads and non-linear loads.
   In the first sentences of the abstract the following changes are made:

   > Spar-type platforms for floating offshore wind turbines are considered suitable for commercial wind farm deployment. To reduce the hurdles of such floating systems becoming competitive, **in-situ aero-hydro-servo-elastic simulations are applied to support conceptual design optimization by including transient and non-linear loads. For reasons of flexibility, the utilized optimization framework and problem are modularly structured so that the setup can be applied to both an initial** conceptual design study for bringing innovative floater configurations to light and a subsequent optimization for obtaining detailed designs.

   In the second last paragraph of the introduction the following changes are made:

   > Thus, this paper aims to demonstrate that through a freer optimization formulation **with in-situ aero-hydro-servo-elastic simulations,** more potential solutions for an advanced spar-type floater design with a higher degree of innovation can be captured**, while already including transient and non-linear loads in the analysis**.

   In the first part of the conclusion the following changes are made:

   > In this paper, an automated optimization approach is applied to a spar-type FOWT system to develop a conceptual innovative floating platform design, which is optimized with respect to the change in hydrodynamics and their impact on the main system performance, while structural, manufacturability, or other constraints are not considered, whereas other advancements are

facilitated. This approach, following a freer optimization formulation **with in-situ aero-hydro-servo-elastic simulations to include transient and non-linear loads already in the system analyses**, is taken in order to be able to explore novel design spaces **that** can be better from a hydrodynamic point of view and show potential for more cost-efficient design solutions, but may require novel structural approaches.

2. *Overview*
The results of section 4 essentially show limitations of the problem formulation (i.e. it is missing critical design constraints). Recasting these oversights as a good thing (i.e. that they suggest truss spar solutions) is spurious. The paper is doing spar not truss-spar optimization – the conclusion that the optimization hints towards superiority of truss-spar configurations is not justifiable. Instead of this, there should be some discussion on what using the computationally costly dynamic analysis has provided. It's still not clear to me and this is core to the paper.

The key objective of the approach and corresponding results is that the design space that is set to be investigated is not limited to (conventional) spar-type floaters, but is let open enough to investigate alternative solutions, still within the modeling capabilities of the utilized framework.
The authors agree that if a conventional spar floater design is to be obtained and the traditional manufacturing processes of welding cylindrical sections together are to be followed, the basic manufacturability constraints should be directly implemented in the optimization problem. However, because this application example is specifically aimed at expanding the design space and not being limited to the conventional floater design, such basic manufacturability constraints are purposefully left out of the optimization problem. This approach lets the optimizer explore novel configurations that are not necessarily covered by conventional floater manufacturing techniques. The resulting designs could be of similar shapes as existing solutions or very different as well. Thus, when setting up the optimization problem, it was also not intended to obtain a truss type spar, but it was left very open in which direction the design would develop from a hydrodynamic point of view.
Due to the manner in which the single cylindrical elements are implemented in the numerical model and connected to each other, the resulting shapes may really look weird. However, the results and potential design solutions found are not expected to be realized as is since it is just a conceptual design optimization study. The shapes should indicate what would be best from a hydrodynamic and system-level performance point of view. Based on these results, it is to think about alternative manufacturing solutions and discuss with manufacturers the corresponding manufacturing constraints, which are then to be integrated into the optimization problem for the subsequent detailed design optimization. The inclusion of references to recent innovative design solutions, such as the TetraSpar or Hexafloat, will assist industry professionals in recognizing the potential.

As an aside:
Michael Borg from Stiesdal was one of my examiners when defending my doctoral thesis. He was especially very interested in this approach and very positive about the results, especially that the optimization yielded a design solution that exhibits similarity to Stiesdal's TetraSpar.

Furthermore, in the first revision round of the paper, Thomas Choisnet from Ideol was one of the reviewers (he commented in the PDF, for which reason his name was identifiable). Based on his comments, it became clear that he also saw the potential for the industry. He even suggested, to add to the potential alternative structural realization methods, that "plated partial bulkheads for loads transfer" could be used, which was hence included in the first revision.

3. *Additional high-level notes*
   It is not clear until section 3.3 what you are actually doing in the study. Saying modular / fully integrated / multi-fidelity optimization etc is abstract and obfuscates what you are doing. Please in plain language both in abstract and introduction say what you are doing succinctly – something like: "In this study, we perform conceptual design optimization for a FOWT spar with in situ aero-hydro-elastic simulations."

   The first sentences of the abstract are restructured and rephrased so that it now becomes clear that only the conceptual design optimization is applied and presented in this paper. Thus, the first sentences now read as follows:

   > Spar-type platforms for floating offshore wind turbines are considered suitable for commercial wind farm deployment. To reduce the hurdles of such floating systems becoming competitive, **in-situ aero-hydro-servo-elastic simulations are applied to support conceptual design optimization by including transient and non-linear loads. For reasons of flexibility, the utilized optimization framework and problem are modularly structured so that the setup can be applied to both an initial** conceptual design study for bringing innovative floater configurations to light and a subsequent optimization for obtaining detailed designs.

   Furthermore, it is added at a later point in the abstract that it is only the "conceptual" (and not the detailed) design optimization presented.

   > The approach for generating an initial but very innovative **conceptual** floater design comprises…

   In the second last paragraph of the introduction, in which the objective and content of the paper are described, some clarifications are added, e.g.:

   > Thus, this paper aims to demonstrate that through a freer optimization formulation **with in-situ aero-hydro-servo-elastic simulations,** more potential solutions for an advanced spar-type floater design with a higher degree of innovation can be captured**, while already including transient and non-linear loads in the analysis**.

4. *Additional high-level notes*
   Please have a native English speaker due a detailed edit if possible. There are still various parts of the paper that are hard to read / difficult to understand because of the English grammar problems. There are many typos and grammatical errors. Apologies that I do not have time to go through all of them.

The entire paper is checked for grammar and spelling, and corrections are made throughout the paper. Furthermore, long sentences that are difficult to read are broken down into several shorter sentences.

5. *Additional high-level notes*
The paper is still very long – some of the text is run-on discussion. An editor could also help with clarity of message and brevity. Having short, concise and clear text and messaging is always better.

The entire paper is revised focusing on shortening and removing duplicate information or information and discussion that stray too far from the topic of the paper. In particular, significant reductions are done in section 2 and 3 (combining the optimization problem definition with the assessment criteria), 4.1 on the DLCs and 4.3 on both the optimizer and the optimization workflow, 5 on the results (removing duplicate information that is already contained in figures or was mentioned before), and 6 on the discussion.

6. *Abstract*
The first sentences talk about a multi-fidelity approach from conceptual to detailed design but only the results for the conceptual design are discussed in the abstract (and paper as far as II can tell)

The first sentences of the abstract are restructured and rephrased so that it now becomes clear that only the conceptual design optimization is applied and presented in this paper. Thus, the first sentences now read as follows:

Spar-type platforms for floating offshore wind turbines are considered suitable for commercial wind farm deployment. To reduce the hurdles of such floating systems becoming competitive, **in-situ aero-hydro-servo-elastic simulations are applied to support conceptual design optimization by including transient and non-linear loads. For reasons of flexibility, the utilized optimization framework and problem are modularly structured so that the setup can be applied to both an initial** conceptual design study for bringing innovative floater configurations to light and a subsequent optimization for obtaining detailed designs.

Furthermore, it is added at a later point that it is only the "conceptual" (and not the detailed) design optimization presented.

The approach for generating an initial but very innovative **conceptual** floater design comprises…

7. *Introduction*
- Small floating wind farms – you mean first generation commercial floating wind farms? Small is ambiguous

The phrase "small floating wind farms" is replaced by "pilot floating wind farms".

- Semi-subs are also deployed. Arguing spar is most mature is not necessarily true and not so important to the paper

This part is removed, and the first sentences of the second paragraph are shortened.

- Figure 1: I don't think it is good to show low resolution graphics from other papers… instead, create your own graphic that illustrates the basic features of the most common topologies for spars

Since the textual description is sufficient for describing briefly some common "advanced" spar-type floater topologies and as the focus should lie on the geometric basis used for the conceptual design optimization presented in Figure 2 (which is now Figure 1), the illustrations (which did not even cover the most common topologies addressed in the paragraph) are removed.

- Sentence in lines 53 to 61 is a long run-on sentence and is hard to read. Please break it down and make sure it is clear

The sentence is split into three shorter sentences that are easier to read.

- "aimed and obtained", "aimed to be obtained"… rephrase, this is not clear

This phrase is rephrased as "aimed at".

- What is in and out of scope should be brought up at the end of the introduction– i.e. the lack of inclusion of the mooring system. The scope of the paper is still unclear by the time I get to the end of the introduction – it is confused by the promise in the abstract for the multi-fidelity framework.

In the second last paragraph of the introduction, in which the objective and content of the paper are described, some clarifications are added, e.g.:

> Thus, this paper aims to demonstrate that through a freer optimization formulation **with in-situ aero-hydro-servo-elastic simulations,** more potential solutions for an advanced spar-type floater design with a higher degree of innovation can be captured**, while already including transient and non-linear loads in the analysis**.

Furthermore, it is directly highlighted what is in and out of scope, as added in the subsequent sentence:

> The conceptual design study and optimization approach, applied in this work, focus on hydrodynamic and system-level analyses **but do not yet include an optimization of the mooring system**.

8. *Forming the basis for innovative floater configurations*

- A table of properties – initial and final – could help in section 2.2

A table is added, comparing the original FOWT system parameter values with those of the initially adjusted system that is used as an initial design for the optimization.

- Section 2.3 is unnecessarily verbose – can you use tables and simplify the text? Section 2.3 and should be combined into section 3, and then streamlined and shortened as section 2.3 has everything to do with the problem set-up

The optimization problem is moved out of section 3 and merged with the content of section 2.3 into a separate section. This is required since the performance criteria are

introduced in these parts but already need to be known for the preprocessing analysis on selecting the most critical DLC. Thus, the separate section is put ahead of the section on the fully modular and automated design optimization. In this separate section, the single elements of the optimization problem are directly derived from the assessment criteria.
Furthermore, the content of section 2.3 is shortened since the table that summarizes the constraints derived from the assessment criteria is already included.

9. *Optimization problem*
See notes on 2.3 – interweave the 2.3 points into section 3

The optimization problem is moved out of section 3 and merged with the content of section 2.3 into a separate section. This is required since the performance criteria are introduced in these parts but already need to be known for the preprocessing analysis on selecting the most critical DLC. Thus, the separate section is put ahead of the section on the fully modular and automated design optimization. In this separate section, the single elements of the optimization problem are directly derived from the assessment criteria.
Furthermore, the specification of the design variables in section 2.2 is as well moved to this optimization problem section.

10. *Fully modular and automated design optimization*
- The paragraph on DLCs can be truncated. Since you are using the IEC, just state that you are using DLCs x,y,z from standard a,b,c. The audience is very familiar with the design standards and you don't need to explain them.

The entire first part on existing standards is removed, and the paragraph on DLCs is shortened.

- In section 3.3.2 there is far too much detail on the optimizer. For a simple structure as a spar, there are many studies that show gradient-based algorithms work well. I do not think you should try to argue that the system is so complex you must use GA or that GA is actually the best choice. Rather, say that for this study you simply used the Gas as these were available in the framework. Future work may look at alternative algorithms and further improvement of the optimization implementation. GA algoirithms are also well known – there is again far too much detail explaining the algorithm. Simply point to a reference on the algorithm is fine. What should be detailed is your specific parameterization of the algorithm (i.e. population size, etc) which you do. A short paragraph would be enough.

The section on the optimizer is significantly shortened and reduced to one paragraph, focusing mainly on the specific parameterization utilized for the study.

- Optimization algorithm section is a bit of a strange label. The optimization algorithm is the GA. What you describe in 3.3.3 is your optimization workflow.

The term "optimization algorithm" is replaced by "optimization workflow" if the GA is not meant.

- Section 3.3.3 is the first section where it is really clear what you are actually doing in the optimization. Consider bringing this forward to the introduction and abstract but state it plainly, something like this: "In this study, we use in situ aero-hydro-elastic simulations to support conceptual design optimization for a FOWT spar."

This information is added in the abstract and introduction as detailed in comments 3 and 6.

- Can you say anything in terms of how often simulations fail? I imagine it could be a lot.

Failing simulations due to negative metacentric height and, hence, poor performance of instable designs occur mainly in the first few generations. Throughout the optimization, there are only around three individuals per generation that still fail to complete the entire simulation length. The number of failing systems becomes clear as well in the result plots for the constraints on the performance criteria, since there are only a few distinguishable results plotted in the first few generations.

This information is now added in the results sections, when presenting the development of the constraints:

> The fact that for **the performance constraints** g_{15} to g_{17}**,** only a few distinguishable individuals are plotted in the first generations is caused by the large number of unstable design solutions that are selected by the optimizer in the first trials. Due to the unsuccessful simulations, the performance variables are set to undesired values, as explained in Sect. 4.3.2, and, hence, **they** are all the same for all failing systems. This is **also** visible throughout the generations, as there is a line at the specified undesired value formed by the individuals that do not complete the simulations successfully**, which, however, are only a few per generation (two to three in the higher generations)**.

- I do not think you need equations 5, 6 or 7 at all… this is trivial information about how optimization works in general

Based on your suggestion, and since the approach is already stated sufficiently clearly in the test, the equations are removed.

11. *Results*

- 31 days!!! That is a heck of a lot of time… and you are not converged at all? It is hard to tell because in figure 4 you start with the initial population which has a much larger spread in performance compared to the subsequent populations.

The "non-convergence" stated previously in the paper was formulated in such a way that it was misleading. Since no convergence tolerance is specified as a constraint, all 10,000 individuals needed to be simulated. Considering the convergence, the conceptual design optimization would have taken about a week. This long duration is just due to the not yet improved numerical code of the FOWT system. Right now, the focus is on improving the numerical model and code. After this, it is expected that the conceptual design optimization will take less than two days.

Some clarification is given in section 5.3:

> The fact that this optimum solution is just found in the last generation states that **the optimizer still tries to improve the result for the objective function since no convergence tolerance has been specified as a stop criterion and the 10,000 simulations have to be completed.**

Furthermore, this issue is discussed in detail in the first paragraph of section 6:

> First of all, the duration of the optimization simulations needs to be dealt with. If an additional stop criterion based on a realistic convergence tolerance had been specified, **only a fraction of** the 10,000 simulations would have **had** to be simulated as the convergence tolerance would have been reached already after around 40 generations. Thus, the conceptual design study would have required just less than a quarter of the actual spent time. However, even around 181 hours---which is more than a week---is still too long for just a conceptual design study**, which should take no more than two days**. The reason behind the currently quite long time required does not lie in the multi-fidelity framework and fully modular optimization problem setup, but rather in the developmental stage of the numerical model for a FOWT system*. While for bottom-fixed wind turbine systems**,** real-time capability of the numerical models based on MoWiT has already been achieved (Feja and Huhn, 2019), the optimization of the code for floating systems is still at an early stage of development. **When this is achieved**, the full simulation of the specified optimization problem will **only** require about one and a half days.
>
> ***An** 800~s load case simulation with a FOWT in **an** irregular sea state and with turbulent wind conditions takes about four and a half hours, which is about 20 times as much as the time to be simulated.

- For figure 4 it would be nice to see the lables in terms of the formal expression rather than design variables so the reader gets a better feel for what they are without having to refer back

The formal expressions of the design variables are used in figure 4.
Furthermore, the legend is removed, and the description of the different colors used in the plots is added in the caption.

- I wouldn't refer to the final design as the "selected optimum" – you know its not optimal. Say instead the best performing individual from the final population

The term "best-performing individual" is used instead of the term "selected optimum".

- Description of what plot colors mean should be in the caption, not in the text.

This is done for figures 3, 4, 5, 7, and 8 (updated numbers).

- Same thing for figure 5, label the plots with the formal expression and not the constraint function variables

The formal expressions of the constraints are used in figure 5.
Furthermore, the legend is removed, and the description of the different colors used in the plots is added in the caption.

- Same thing in table 6, use formal expression for DVs, constraints and objective function

The formal expressions of the design variables, constraints, and objective function are used in table 6.
This is done in table 8 as well.

- It is not clear if "these individuals" as in line 401 on page 4.2 are from the first generation or final generation. As they obey the constraints (as far as I can see), they are from the final population? Make sure that it is explicit. How did you select these individuals? Is it random? And

is their ordering random? Their objective function performance is wildly different- if it were ordered from lowest to highest

It is clarified that only the individuals that comply with all optimization constraints are further assessed in this section. However, it is also clarified that the focus does not yet lie on the objective function result but rather on showing the wide diversity of potential innovative floater geometries.

> The geometric design variables of these individuals **that meet all constraints** are **presented** in Fig. 5. From these individuals **that** comply with all constraints, seven examples **out of different generations** are selected to demonstrate the diversity of potential innovative floater geometries**, not yet focusing on their performance with respect to the objective function**.

The individuals that comply with all constraints originate from almost all generations (apart from the first), which becomes clear in the development plots (the dark recolored crosses), as well as in table 7 by the figures corresponding to the selected exemplary geometries.

- In figure 6, you can see that there are a lot of really weird designs. It is quite easy to implement basic manufacturability constraints for example which would help avoid getting such weird designs. Having such weird results undermines to a degree the overall credibility of the work – this is dangerous as an industry person looking at these results would likely be very dismissive of the work.

Some detailed answers to this are provided in the answer to comment 2. For further clarification, the objective of the approach is added here as well:

> Looking at the floater geometries presented in Fig. 5, it becomes clear that not all of these shapes can be realized with conventional manufacturing solutions, where cylindrical sections are welded together. It has to be emphasized that these results are solely based on the hydrodynamic and system-level analyses, as specified within the optimization problem, as well as on the advancements taken into account in Sect. 3**,** which clearly intend the utilization of alternative and innovative structural realization approaches **and let the optimizer explore novel configurations that are not necessarily covered by conventional floater manufacturing techniques**.

Furthermore, the formal expressions of the design variables are used in figure 6. Additionally, the legend is removed, and the description of the different colors used in the plots is added in the caption.

- The comparison of the design results to figure 7 also is strange. Truss type spars are different than what you are modelling. There are simulation tools out there to design such things, but saying that your spar framework can help identify structures like truss that could be sought is a big leap… its also a big leap to draw a link between the example designs and the two truss spars from the literature. I don’t think you can do so based on the results you have.

The approach does not aim at truss type spars or any other specific geometries, but rather left the design space and potential geometry open. The reference to the designs presented in figure (now) 6 shall help industry professionals recognize the potential of this “freed” approach. The authors refer to the detailed answer given to comment 2.

- "one and only objective function" is strange wording… just say objective function. Delete the entire first sentence of section 4.3 – this is how basic optimization works and does not need explanation.

Yes, considering the background of the readership, the first paragraph is not required and hence deleted.

- There is a lot of redundancy in section 4.1 through 4.3 – you can much more quickly get to the point around the final best performing individual and eliminate making overreaching statements about the capability.

Section 4 is shortened and condensed. Unnecessary information, e.g., on the different colors used in the plots, is removed.

- The basic issues with the final design related to lack of constraints related to manufacturability and/or structural analysis should have been corrected before publication as they are easy to implement and appear in various prior studies (for example tower, jacket and monopile optimization from NREL, Stuttgart, and elsewhere). I do not think rebranding it as hinting towards truss spar solutions is justifiable. If the paper were to do truss spar optimization it should do it and would need to reformulate the model to account for the truss elements – in other words, it would be an entirely different study. ***Instead of focusing on the truss, please expand on what using the dynamic analysis in situ has added in value compared to using static or quasi-static analysis.***

Some detailed answers to this are provided in the answer to comment 2.

12. *Discussion*

- Recommend shortening substantially the discussion section. They are far too detailed. Every paragraph in the section including the bulleted paragraphs can be shortened likely by half. Be clear and concise.

All parts of the discussion section are condensed. Duplicate information or discussions that stray too far from the topic of the paper are removed.

- The lines from 605 on overstate things. It would be better to say that future work will incorporate constraints on stress, buckling and manufacturability to ensure that the designs are realistic but also allowing for the exploration of a wide range of novel concepts.

The last sentence of this paragraph has been removed, and it is more focused on the future work on incorporating structural integrity checks and constraints on stress and buckling.

- I don't think you need to speak to LCOE optimization unless you are going to speak to the elements across LCOE that the spar design impacts… i.e. where the couplings will be that require a more holistic approach

Since the final paragraph on addressing LCoE optimization is too far from the topic of the paper, it is removed entirely from the discussion.

13. *Conclusion*

The last sentence is still an overreach… what can you conclude from this work? In one to two sentences

The last sentence of the conclusion on the multi-fidelity framework is deleted and two final concluding sentences are added, focusing more on the overall objective of the paper and the results:

> Thus, the presented approach of expanding the design space and purposefully leaving out basic manufacturability constraints in the conceptual design study lets the optimizer explore novel configurations that are not necessarily covered by conventional floater manufacturing techniques. The results of the presented conceptual design optimization exhibit similarities to recent innovative design solutions, such as Stiesdal's TetraSpar and Saipem's Hexafloat, which emphasizes the potential for the industry.