# Behavioral intention, perception and user assessment in an immersive virtual reality environment with CFD simulations

*Supplementary Information*

## Free access to VR application and walkthrough video

The Virtual Garage with Case#5 is freely downloadable on GitHub: XXX (TBA)

A walkthrough video of the Case#5 is available on YouTube: https://www.youtube.com/watch?v=iJV4jQn7VQY.

## The constructs that are not adopted in the conceptual model:

There were more constructs than we discussed in our study were appeared in the literature but were not adopted in our conceptual model. First, perceived usefulness and use motivation were employed by researchers in similar contexts. Given the context of our research, we found these constructs superficial to adequately evaluate the behavioral intention. Instead, constructs such as learning value and content value can already give reliable outcomes to interpret behavioral intention from perceived usefulness and use motivation point of view. Secondly, extrinsic value is an emerging factor in behavioral intention since immersive technologies are becoming more invasive in engineering and education. Performance expectancy, content value and learning value do include extrinsic aspects of individuals' behavioral intention to use. Thus, we did not separately measure the extrinsic value in our conceptual model. Furthermore, simulator sickness was considered a significant factor that negatively affects behavioral intention. Due to its vivid effect, we did not extend our model with simulator sickness, which clearly discourages users to adopt VR experiences. Lastly, researchers expanded the UTAUT2 utilizing the satisfaction scale in various contexts. However, in our context, the effect of satisfaction on behavioral intention may not be a sound scale to interpret behavioral intention, because it is still not clear from which point of view the satisfaction should be incorporated into the model. To sum up, there are surely more constructs that can be included to explore various aspects of VR in behavioral intention. Nevertheless, we only considered and discussed the ones given the scope of our study.

## Details on Case#5: water treatment basin

Water treatment basins have long been used in industrial-scale processes in order to remove bacteria or other contaminants. Chemicals such as chlorine - valued for both its effectiveness and low cost - are typically used within the water basin to eliminate disease-causing microorganisms in water. The performance of water treatment should be adequate to ensure the disinfection process. CFD simulations are useful tools in the design and analysis of the water treatment performance of a water basin investigating both design and operating parameters. The water treatment basin is an interesting example comprising several aspects of chemical engineering, as well as enabling an introductory case for intensified processes.

In Case#5, students are expected to configure a water treatment basin that satisfies design constraints such as chlorine level and pressure drop. Baffle orientation, size and length are a set of parameters to be optimally chosen by students to comply with constraints. CFD simulations were performed by COMSOL, adopting a case study available on COMSOL's model database. More information about CFD simulations can be found as follows: https://www.comsol.com/model/water-treatment-basin-14049/.

Intended learning outcomes are aligned with course content and assessment. They are explicitly defined hard skills and competencies that students are expected to acquire after the learning experience. At the end of the simulations a student will be able to:

- identify design parameters and principles of the water treatment basin,
- identify parameters to predict the performance of water treatment basin,
- predict the effect of design parameters on the performance of the water treatment basin,
- predict the fluid flow patterns for different baffle wall configurations,
- use output data to critically compare design parameters,
- differentiate design parameters by interpreting output data from simulations,
- determine the optimal values for each design parameter,
- formulate a final design for the water treatment basin.

## Knowledge tests: multiple choice questions

The knowledge test was developed to measure the knowledge gain with eight dedicated questions during the experimental intervention. Students filled the same test before and after the VR experience. Three choices were provided in each question with one correct answer and two credible distractors. The test was validated by peer chemical engineers. Questions in the knowledge tests are shown as follows (Note that Asterisk (*) implies the correct choice.):

1. What parameters are important in the design of a water treatment basin?

- Chlorine residuals, velocity profiles, flow patterns, ambient pressure
- Residence time, chlorine residuals, velocity profiles, flow patterns (*)
- Installation cost, ambient temperature, residence time, flow patterns

2. Which of the following best illustrates the significance of the pressure loss in the design of a water treatment basin?

- Pressure loss determines the inlet velocity to reduce operating cost
- Pressure loss determines the size of the pump forcing the flow through the basin (*)
- Pressure loss determines the chlorine residuals and residence time distribution

3. Which of the following effects do baffle walls have on the design of water treatment basins?

- Eliminate dead zones, lower pressure loss, better mixing
- Better mixing, higher pressure loss, elimination of dead zones (*)
- Lower pressure loss, better mixing, higher chlorine residuals

4. Which of the following parameters are necessary to determine the number of baffle walls in a water treatment basin?

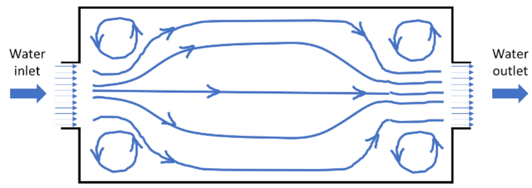
- Pressure loss, chlorine concentration, inlet velocity, flow patterns
- Flow patterns, ambient temperature, chlorine concentration, velocity profiles
- Velocity profiles, pressure loss, flow patterns, chlorine concentration (*)

5. Which of the statements below is correct?

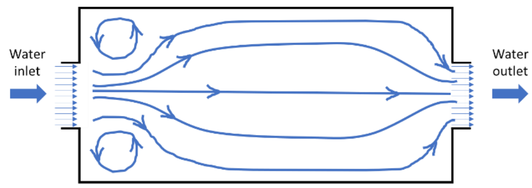
- The orientation of the baffle walls does not significantly influence on residence time and pressure loss.

- The concentration profile, combined with the flow field, shows regions where the chlorine concentration may increase.
- The regions immediately behind the baffle walls have a slightly lower chlorine concentration since these are recirculation zones for the flow (*)

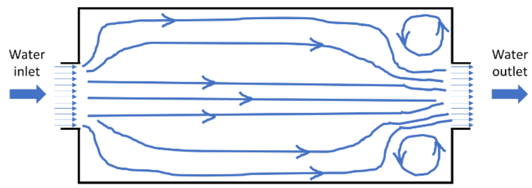
6. Which one of the following correctly illustrates the turbulent fluid flow throughout a water basin? (*d)



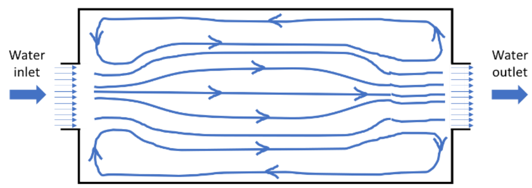

**a**




**b**

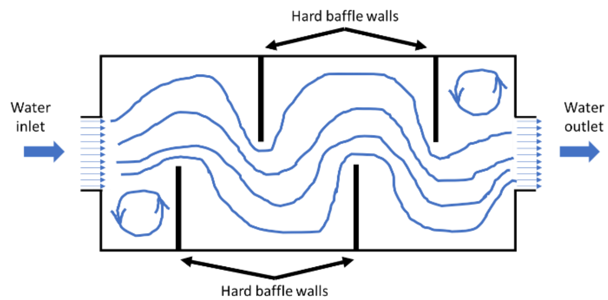



**c**

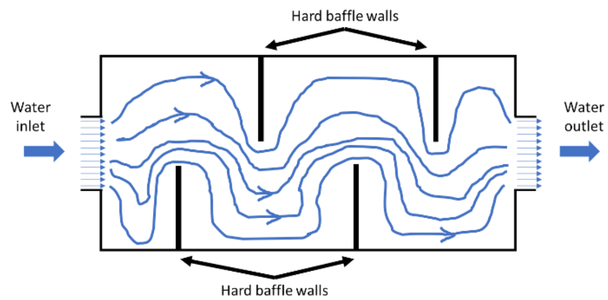



**d**

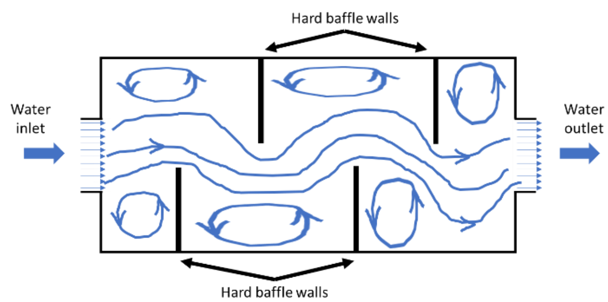
7. Which one of the following correctly illustrates the turbulent fluid flow throughout a water basin? (*c)



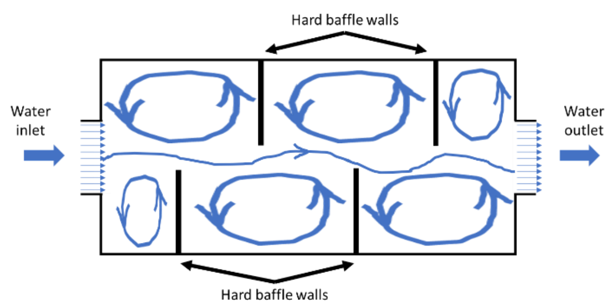

a




b

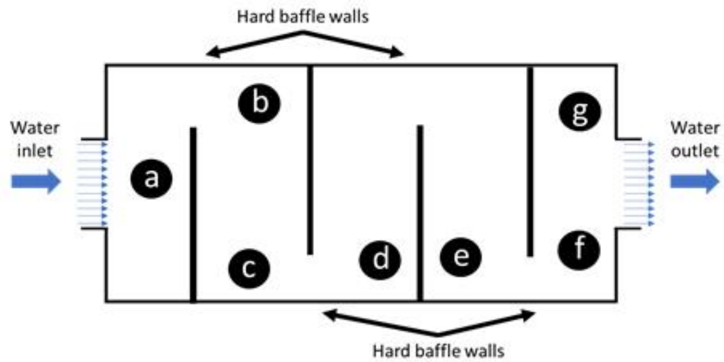



c




d

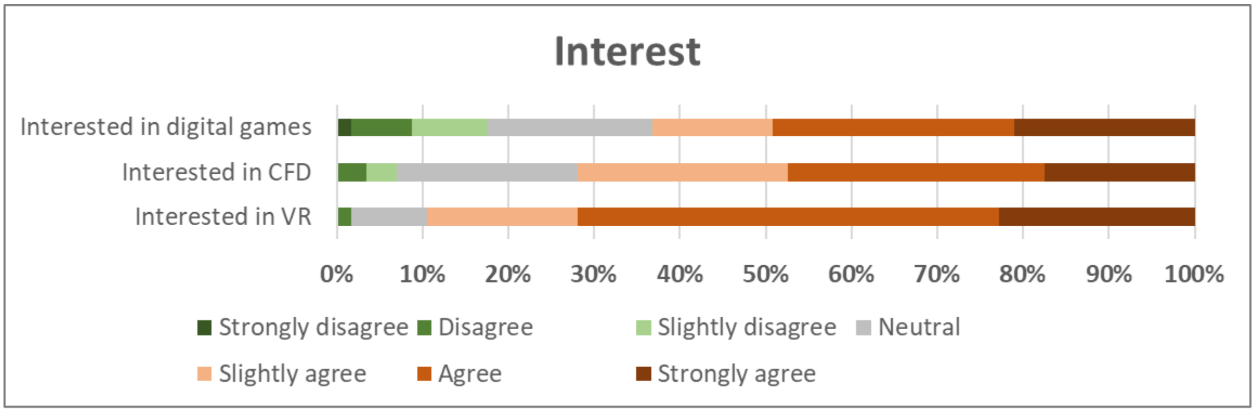
8. Compare the chlorine concentrations of given points in the water basin.

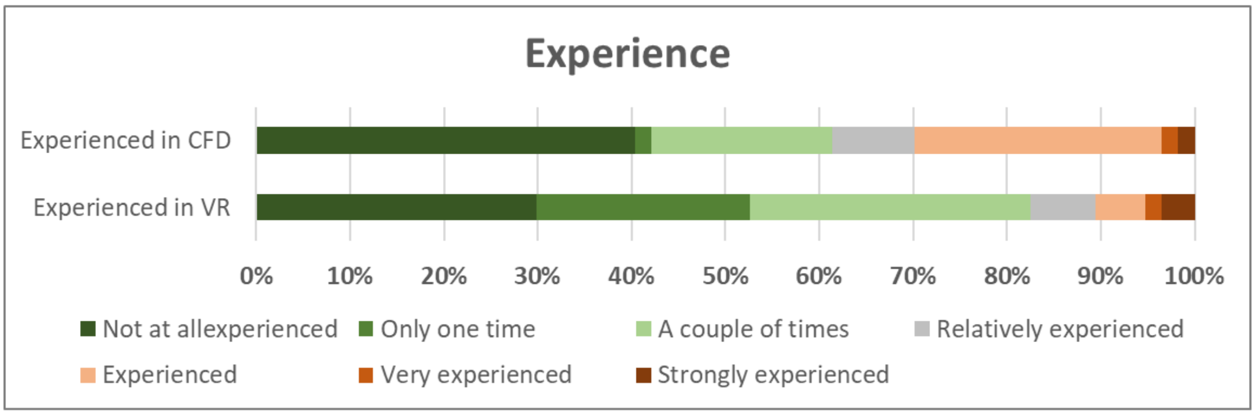



| | > (bigger) | < (lower) | ≈ (approximately equal) |
|---|---|---|---|
| a ..... b | ⬭ | ⬭ | ⬭ |
| b ..... c | ⬭ | ⬭ | ⬭ |
| c ..... d | ⬭ | ⬭ | ⬭ |
| d ..... e | ⬭ | ⬭ | ⬭ |
| g .....f | ⬭ | ⬭ | ⬭ |

## Participants experience and interest – supporting information

Respondents came from a diverse background with regard to their interest, experience and habit. Figure A illustrates the pre-test results completed by students before the VR experience.



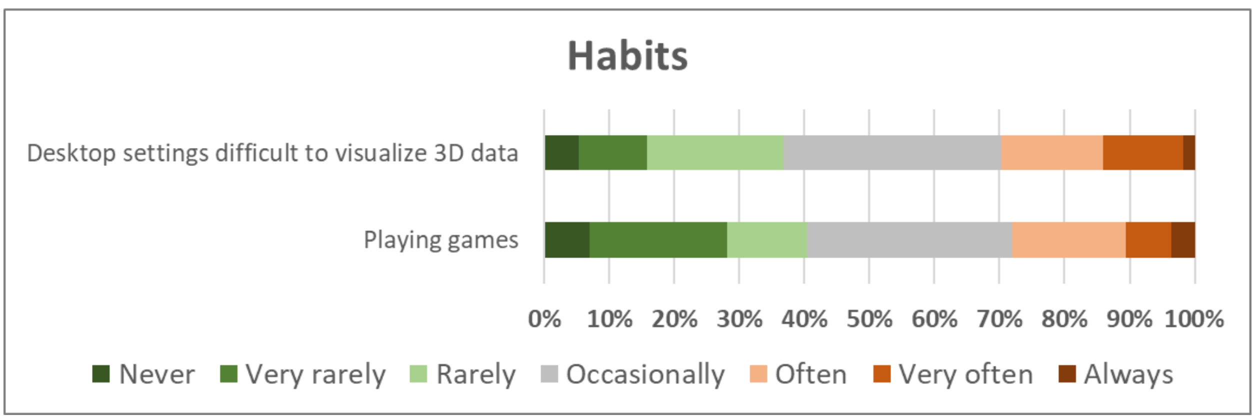




*Figure A. Interest, experience and habit of participants.*

## Detailed HTMT confidence intervals:

*Table A. Bootstrapped Discriminant Validity Hetrotrait-Monotrait Ratio (HTMT) Method: HTMT Confidence Interval Bias Corrected.*

| Confidence Intervals Bias Corrected | | | | | |
|---|---|---|---|---|---|
| | Original Sample | Sample Mean | Bias | 5.0% | 95.0% |
| SE -> EE | 0.873636 | 0.870609 | -0.00303 | 0.688268 | 0.99508 |
| IV -> CV | 0.819416 | 0.832651 | 0.013235 | 0.600474 | 0.991098 |
| CV -> BI | 0.871303 | 0.870034 | -0.00127 | 0.743181 | 0.983076 |
| IV -> BI | 0.848177 | 0.843867 | -0.00431 | 0.68377 | 0.965629 |
| PE -> LV | 0.908571 | 0.913721 | 0.00515 | 0.828865 | 0.959928 |
| IV -> FT | 0.820819 | 0.811197 | -0.00962 | 0.63518 | 0.952241 |
| LV -> BI | 0.883408 | 0.879776 | -0.00363 | 0.770044 | 0.950255 |
| PE -> IV | 0.830518 | 0.837533 | 0.007015 | 0.652589 | 0.945942 |
| PE -> CV | 0.794179 | 0.815923 | 0.021744 | 0.621182 | 0.937719 |
| LV -> CV | 0.806073 | 0.805938 | -0.00014 | 0.617876 | 0.934856 |
| PI -> IV | 0.765012 | 0.74872 | -0.01629 | 0.533718 | 0.915574 |
| LV -> IV | 0.804684 | 0.799863 | -0.00482 | 0.648465 | 0.911234 |
| IV -> EE | 0.715806 | 0.706975 | -0.00883 | 0.491944 | 0.894838 |
| PE -> BI | 0.815067 | 0.820086 | 0.005019 | 0.707965 | 0.892204 |
| FT -> CV | 0.738078 | 0.751006 | 0.012928 | 0.567493 | 0.874604 |
| PI -> PE | 0.757664 | 0.75284 | -0.00482 | 0.581326 | 0.870946 |
| PI -> BI | 0.735188 | 0.73068 | -0.00451 | 0.554624 | 0.86586 |
| PI -> CV | 0.709287 | 0.715067 | 0.00578 | 0.506829 | 0.85144 |
| LV -> FT | 0.655576 | 0.642283 | -0.01329 | 0.394994 | 0.826293 |
| PI -> LV | 0.675822 | 0.66315 | -0.01267 | 0.467886 | 0.815751 |
| PI -> FT | 0.602253 | 0.592899 | -0.00935 | 0.367186 | 0.795582 |
| FT -> BI | 0.66578 | 0.658851 | -0.00693 | 0.501482 | 0.789671 |
| FT -> EE | 0.57156 | 0.558031 | -0.01353 | 0.317198 | 0.786116 |
| SE -> FT | 0.597966 | 0.593537 | -0.00443 | 0.383143 | 0.783559 |
| PE -> FT | 0.548565 | 0.567855 | 0.01929 | 0.308275 | 0.781213 |
| PI -> EE | 0.44879 | 0.449994 | 0.001203 | 0.168404 | 0.76912 |
| SE -> IV | 0.513996 | 0.512774 | -0.00122 | 0.26984 | 0.754429 |
| SE -> PI | 0.381937 | 0.394629 | 0.012692 | 0.16151 | 0.656423 |
| EE -> BI | 0.323873 | 0.330506 | 0.006633 | 0.100312 | 0.611726 |
| SE -> BI | 0.312682 | 0.324938 | 0.012256 | 0.098549 | 0.604009 |
| LV -> EE | 0.24492 | 0.285442 | 0.040522 | 0.086306 | 0.567267 |
| PE -> EE | 0.300168 | 0.355549 | 0.055381 | 0.132033 | 0.563965 |
| SE -> LV | 0.236208 | 0.301996 | 0.065788 | 0.084842 | 0.43605 |
| SE -> PE | 0.232104 | 0.294641 | 0.062537 | 0.102985 | 0.423965 |
| SE -> CV | 0.231883 | 0.296559 | 0.064677 | 0.090903 | 0.37932 |
| EE -> CV | 0.2171 | 0.299273 | 0.082173 | 0.090783 | 0.336439 |

## The VIF values:

*Table B. The VIF values. We examined the collinearity to mitigate the effects of bias between constructs. The construct's tolerance (VIF) value was lower than 5 in all items, thus eliminating collinearity.*

| Collinearity | |
|---|---|
| Items | VIF |
| | < 5 |
| BI1 | 4.440 |
| BI2 | 2.816 |
| BI3 | 3.076 |
| CV1 | 1.302 |
| CV2 | 1.556 |
| CV3 | 1.358 |
| EE1 | 2.957 |
| EE2 | 3.024 |
| EE3 | 2.632 |
| EE4 | 2.709 |
| FT2 | 1.705 |
| FT4 | 1.826 |
| FT5 | 1.812 |
| IM1 | 2.286 |
| IM2 | 2.567 |
| IV1 | 1.811 |
| IV2 | 1.749 |
| IV3 | 1.515 |
| IV4 | 1.467 |
| LV2 | 2.643 |
| LV3 | 3.436 |
| LV4 | 2.482 |
| PE1 | 2.416 |
| PE2 | 2.886 |
| PE3 | 1.758 |
| PE4 | 2.586 |
| PI1 | 1.875 |
| PI2 | 1.809 |
| PI3 | 2.747 |
| PI4 | 2.878 |
| SE1 | 3.114 |
| SE3 | 3.344 |
| SE4 | 1.672 |