RESULTS OF 3RD BLIND SIMULATION COMPETITION

Simulation of slabs reinforced with conventional flexural reinforcement and fibres subjected to punching loading configuration

1. Introduction

This document presents the results of the 3rd Blind Simulation Competition carried out within the scope of the *fib* WP 2.4.1 *Modelling of Fibre Reinforced Concrete Structures*. The object of the benchmark is to predict some important behaviour aspects of a slab reinforced with conventional flexural reinforcement and fibres subjected to punching loading configuration.

This benchmark and the rules of the competition were announced in Februray 2023. Information about the properties of the materials at the age of 22 days was communicated at 10th April 2023. A total of 25 teams submitted 29 proposals, from which 25 proposals were considered in the final classification of the competition, corresponding to those submitted in proper time and format. Experiments were conducted at 18th and 27th of July 2023 on two slab prototypes for the appraisal of the predictive performance of the simulation proposals. The last test was transmitted in real time through a youTube channel. The videos of the tests can be found in the following links: https://youtu.be/Ru0szbEXWCo, https://youtube.com/live/d6kIRS6_tPQ. The experimental results and those of the simulations were then analysed. The final classification was communicated to the participants on 29th September 2023.

The following sections of the current report present the name of the participants, the experimental results, the numerical results, and the performance of the numerical predictions.

2. Name of participants

This section presents the name of the authors of the proposals considered in the final classification of the competition. There were 25 teams of participants with a total of 89 persons involved, 28 institutions from 17 different countries including Brazil, Canada, China, Czech Republic, Egypt, Germany, Hungary, India, Italy, Norway, Portugal, South Korea, Spain, Switzerland, The Netherlands, United Arab Emirates and United States of America, from which 5 companies of structural design and development of software based on the finite element method (FEM), and 23 universities and research institutes. Table 1 includes a list of the participants and their affiliation, sorted by alphabetical order.

Table 1. List of participants and affiliation, sorted by alphabetical order

Name of the participants	Affiliation(s)
Alejandro Nogales[1], Stanislav Aidarov[1], Andrea Monserrat[1], Nikola Tošić[1], Albert de la Fuente[1]	[1]Universitat Politècnica de Catalunya, Spain
Alexander Kagermanov[1]	[1]Eastern University of Applied Science (OST), Switzerland
Chen Lin[1], Guomin Ji[1], Terje Kanstad[1]	[1]Norwegian University of Science and Technology
Eric Renã Zavitzki Schimanowski[1], Américo	[1]Federal University of Rio Grande do Sul (UFRGS), Porto Alegre, RS, Brazil

Campos Filho[1], Paula Manica Lazzari[1], Bruna Manica Lazzari[2]	[2]Pontifical Catholic University of Rio Grande do Sul, Porto Alegre, RS, Brazil
Federico Accornero[1], Liu Xiang[1], Lin Zijie[1], Yang Xiaosheng[1], Tan Mengxi[1], He Yuting[1], Yuan Wenhao[1]	[1]College of Engineering, Shantou University, Shantou-China
Federico Accornero[1], Peiwei Lv[1], Zimin Xie[1], Jianwei Ji[1], Qi Yang[1], Haodian Zhu[1], Jian Yang[1], Sijie Yuan[1]	[1]College of Engineering, Shantou University, Shantou-China
Gerrit E. Neu[1], Vladislav Gudžulić[1], Michael Hofmann[1], Guenther Meschke[1]	[1]Institute for Structural Mechanics, Ruhr University Bochum, Germany
Inkyu Rhee[1]	[1]Chonnam National University, Gwangju, South Korea
Jikai Zhou[1], Mingjue Wang[1], Ruihua Ruan[1], Wei Xu[1], Jiyao Wang[1]	[1]College of Civil and Transportation Engineering, Hohai University, China
Jikai Zhou[1], Tao Liang[1], Jinyu Zhao[1], Yue Wu[1], Yating Tai[1]	[1]College of Civil and Transportation Engineering, Hohai University, China
José Joaquín Ortega[1], Rena C. Yu[2], Elisa Poveda[2]	[1]Universidad Politécnica de Madrid, Spain [2]Universidad de Castilla-La Mancha, Spain
Kryštof Toman[1], Iva Broukalová[1]	[1]Czech Technical University in Prague
Lex van der Meer[1], Krishna Ajithkumar Pillai[1], Giel van Lanen[1], Jasper van Alphen[1], Niki Loonen[1]	[1]ABT bv, The Netherlands
Mahdi Ben Ftima[1], Bruno Massicotte[1]	[1]Polytechnique Montréal
Marcílio M. A. Filho[1]	[1]ISISE Institute for sustainability and Innovation in Structural Engineering, University of Minho
Marco Bolognin[1], Ab van den bos[1], Pim van der Aa[1]	[1]NLyse Consultants b.v.
Massimo Petracca[1], Valentina Bogatkina[1], Guido Camata[2], Mohammad AlHamaydeh[3]	[1]ASDEAsoft, Italy [2]Universita degli Studi Gabriele d'Annunzio Chieti e Pescara, Italy [3]American University of Sharjah, United Arab Emirates
Muhammad Hamza[1], Hamed Salem[2]	[1]Applied Science International, LLC, USA [2]Cairo University, Giza, Egypt
Peter K. Juhasz[1], Peter Schaul[1]	[1]JKP Static Ltd. -- Budapest, Hungary
Pradeep S[1], Ananth Ramaswamy[1]	[1]Indian Institute of Science, Bangalore, India
Rafael Sanabria[1,2], Leandro Mouta Trautwein[1], Luiz Carlos de Almeida[1]	[1]University of Campinas, Campinas, SP, Brazil [2]TU Delft, Netherlands
Sören Faustmann[1], Nils-Christian Rokoß[1], Oliver Fischer[1]	[1]Technical University of Munich, Germany
Trevor D. Hrynyk[1]	[1]University of Waterloo, Waterloo, Ontario, Canada
Yanli Su[1], Chang Wu[1]	[1]Southeast University, Nanjing, China

3. Experimental results

Two slabs were subjected to punching loading, according to the load configuration indicated in the rules of the competition. Figure 1 displays the experimental results.

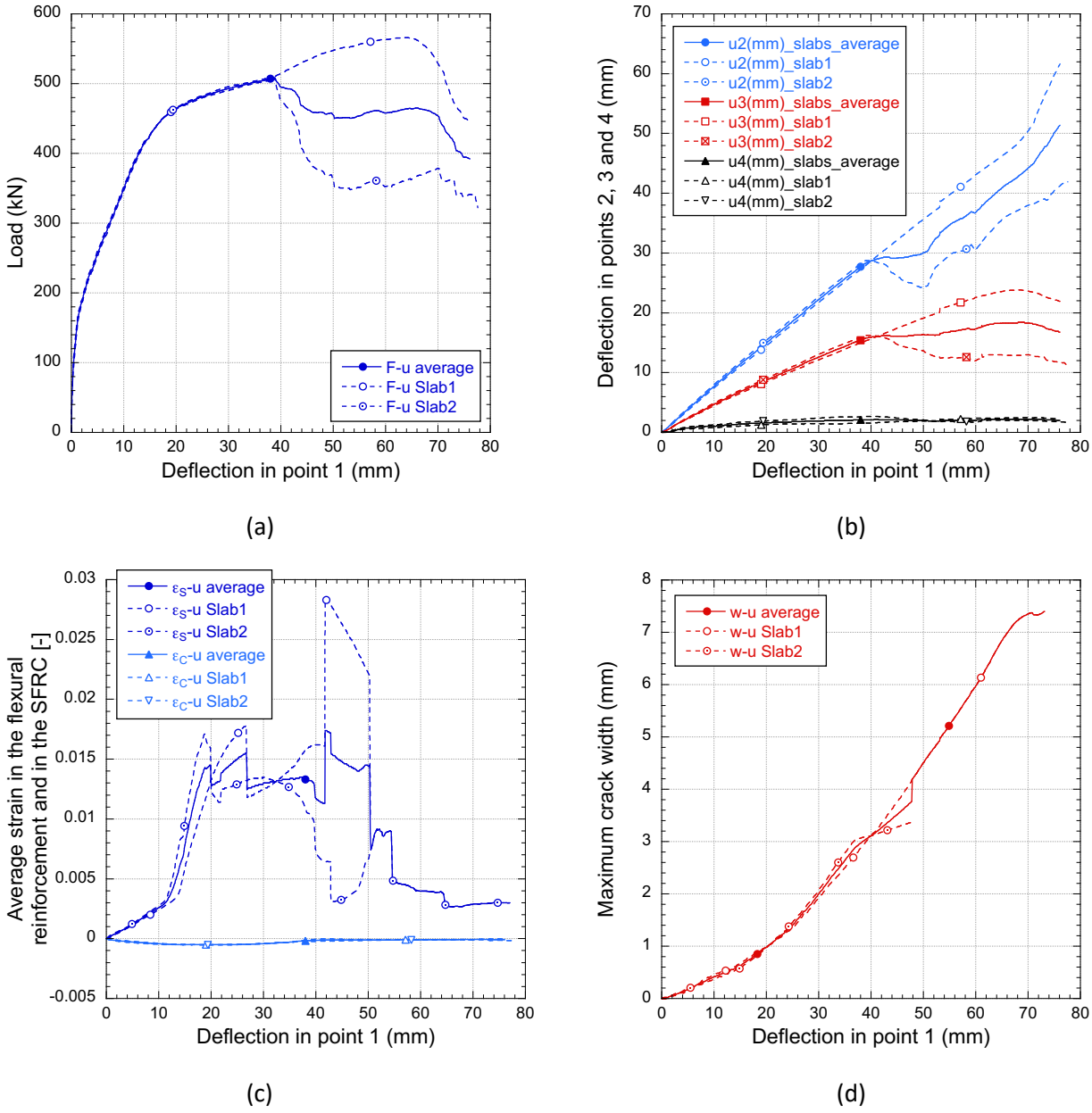

Figure 1. Experimental results and average curves of load versus deflection in point 1 (a), deflection in points 2, 3 and 4 versus deflection in point 1 (b), average tensile strain in the flexural reinforcement and in the SFRC versus deflection in point 1 (c), and maximum crack width versus deflection in point 1 (d)

4. Results of the simulations

Figure 2 and Figure 3 show the experimental average, numerical envelope and numerical predictions of all participants. Figure 2 includes the curves of load versus deflection in point 1, average strain in the flexural reinforcement versus deflection in point 1, and average strain in the SFRC versus deflection in point 1. Figure 3 includes the curves of deflection in points 2, 3 and 4 versus deflection in point 1, and maximum crack width versus deflection in point 1. The results are displayed up to a deflection of 60 mm, which covers the deflection corresponding to peak load of most predictions.

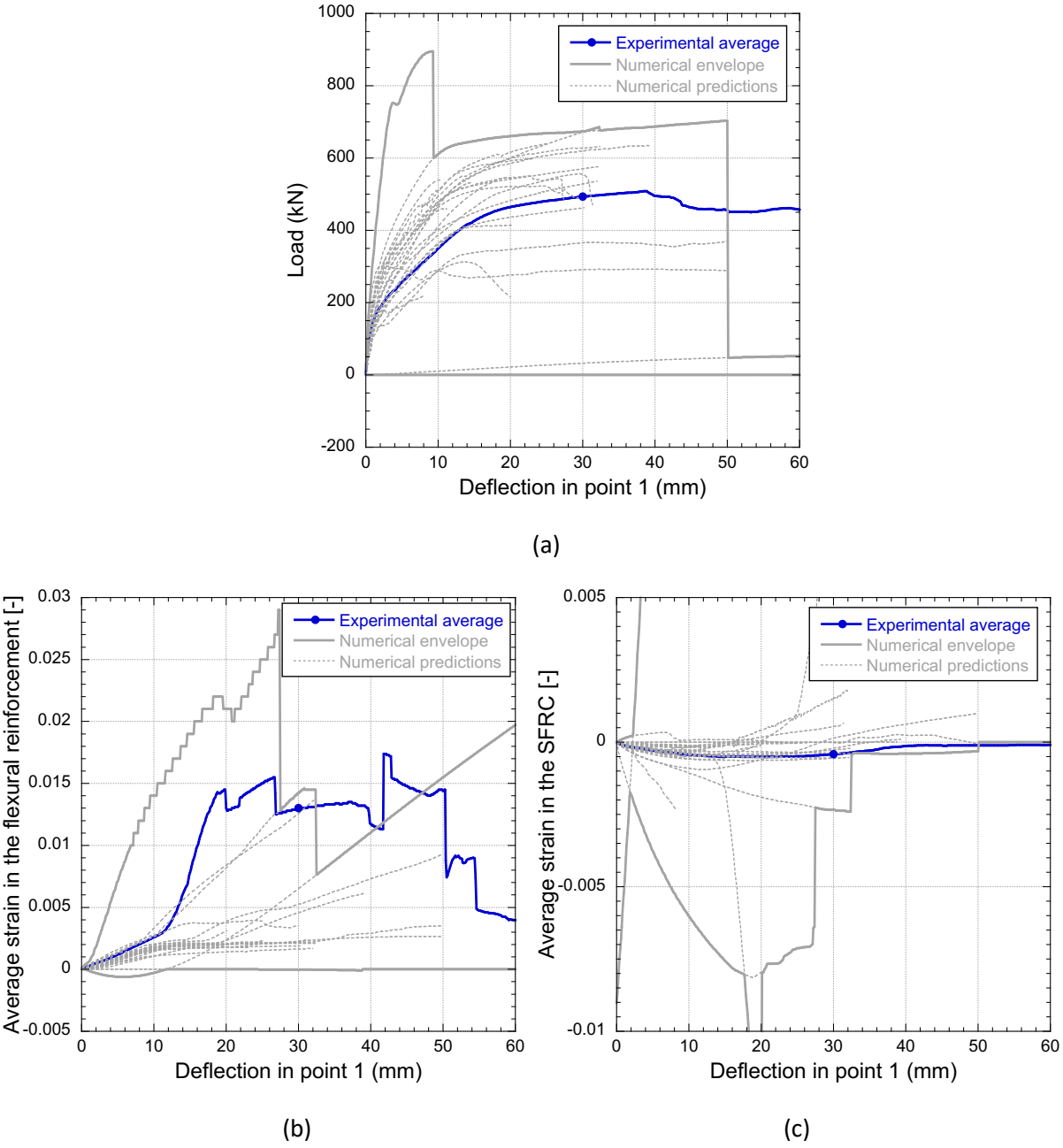

Figure 2. Experimental average, numerical envelope, and numerical predictions of all participants regarding the: load versus deflection in point 1 (a), average strain in the flexural reinforcement versus deflection in point 1 (b), and average strain in the SFRC versus deflection in point 1 (c)

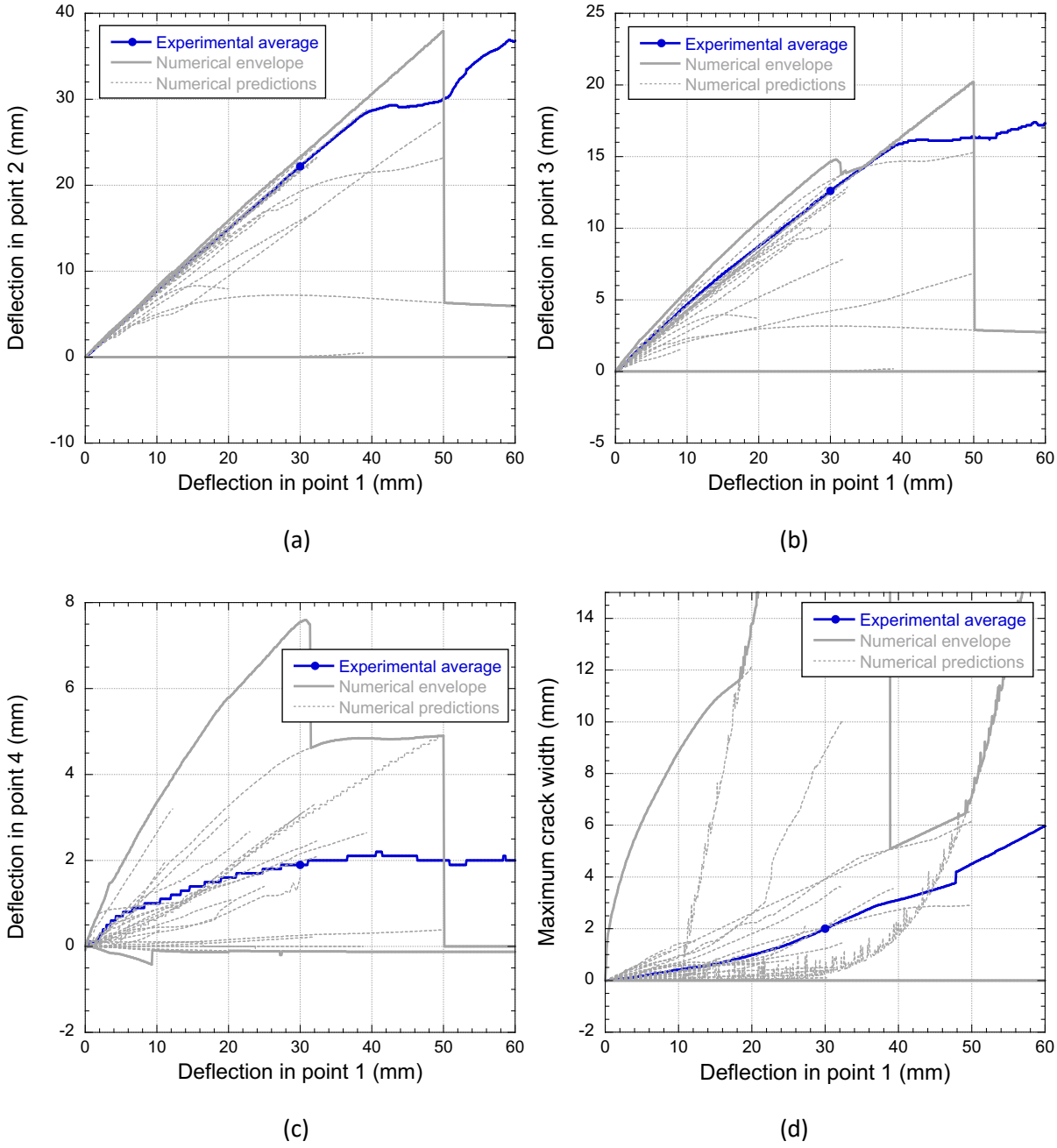

Figure 3. Experimental results, numerical envelope, and numerical predictions of all participants regarding the: deflection in point 2 versus deflection in point 1 (a), deflection in point 3 versus deflection in point 1 (b), deflection in point 4 versus deflection in point 1 (c), and maximum crack width versus deflection in point 1 (d)

5. Predictive performance of the simulations

For each participant, the predictive performance of the numerical simulation was computed after performing the tests, according to the following rules:

1. The experimental average was computed from the results of the two slabs.

2. The numerical results of each participant were compared with the experimental average up to the greatest of the displacement corresponding to the numerical peak load u_{num}^{Fmax} or the displacement corresponding to the experimental peak load u_{exp}^{Fmax}. It means that a) if the final displacement of the

numerical curve is smaller than u_{exp}^{Fmax}, the numerical curve was completed with zero values from u_{num}^{Fmax} up to u_{exp}^{Fmax} and compared to the experimental curve up to u_{exp}^{Fmax}; b) if the final displacement of the numerical curve u_{num}^{Fmax} is greater than u_{exp}^{Fmax}, the experimental curve was completed with zero values from u_{exp}^{Fmax} up to u_{num}^{Fmax} and compared to the numerical curve up to u_{num}^{Fmax}.

3. The normalised root mean square root $NRMS_F$ of the numerical prediction of load was calculated as:

$$NRMS_F = \frac{1}{F_{exp}^{max}} \sqrt{\frac{\sum_\kappa (F_{exp}^\kappa - F_{num}^\kappa)^2}{n}} \quad (1)$$

where κ corresponds to the records, F_{exp}^κ is the experimental value of load of the record κ, F_{num}^κ the numerical value of the record κ, n is the number of scan readings, and F_{exp}^{max} is the maximum of the experimental load. Equivalent equations are used to compute the *NRMS* of the deflection in points 2, 3 and 4 $NRMSu_2$, $NRMSu_3$ and $NRMSu_4$, respectively, the average strain in the flexural reinforcement $NRMS\varepsilon_s$, the average strain in the SFRC $NRMS\varepsilon_c$, and the maximum crack width *NRMSw*.

4. The score of each participant was calculated according to the following expression:

Score = $0.25NRMS_F + 0.05NRMSu_2 + 0.05NRMSu_3 + 0.05NRMSu_4 + 0.2NRMS\varepsilon_s + 0.2NRMS\varepsilon_c + 0.2NRMSw$ (2)

Table 2 includes the predictive performance of the simulations of the 26 teams of participants. Note that the order of participants is random and does not coincide with that of Table 1, for the sake of confidentiality.

Table 2. Predictive performance of the results presented by the participants, shown in random order.

Partici-pant no.	*NRMS F*	*NRMS* u_2	*NRMS* u_3	*NRMS* u_4	*NRMS* ε_s	*NRMS* ε_c	*NRMS w*	Score	Classif.
1	0.3798	0.3212	0.3260	0.3938	0.4531	1.729	0.3058	0.6446	10
2	0.2925	0.2384	0.2401	0.2507	0.2886	4.461	0.6879	1.197	22
3	0.2796	0.2433	0.2446	0.3005	0.2944	0.6070	0.2768	0.3450	2
4	0.4314	0.3503	0.3559	0.4270	0.4924	1.409	0.3043	0.6057	7
5	0.5424	0.4257	0.4086	0.7779	0.3926	2.385	0.3336	0.8385	20
6	0.4863	0.3674	0.3748	0.4373	0.5094	1.393	0.3102	0.6230	8
7	0.5926	0.3762	0.3859	0.4750	0.5139	1.506	0.3147	0.6769	13
8	0.3118	0.2799	0.2866	0.9764	0.4652	2.016	0.2859	0.7085	17
9	0.1852	0.09471	0.09464	0.1362	0.3687	0.5550	0.1155	0.2704	1
10	0.4902	0.3704	0.3788	0.4708	0.5115	1.474	0.9260	0.7659	18
12	0.5340	0.3789	0.3879	0.4665	0.5146	1.589	0.3133	0.6785	14
13	0.2836	0.2831	0.3355	0.9834	0.4341	1.520	0.7065	0.6832	16
14	0.5168	0.3748	0.3833	0.4619	0.5133	1.474	0.3123	0.6501	11
15	0.4355	0.3481	0.3539	0.4123	0.4937	1.199	0.3036	0.5640	6
16	0.2644	0.2566	0.2746	0.4445	0.4712	3.572	0.2871	0.9809	21
17	0.4175	0.3343	0.3388	0.3866	0.4896	0.9751	0.2975	0.5098	5
18	0.5097	0.3745	0.3828	0.4560	0.5133	1.488	0.3122	0.6507	12
19	0.4976	0.3726	0.3807	0.4836	0.5127	1.437	0.3215	0.6406	9
20a	0.4078	0.3378	0.3429	0.4595	0.5392	17.11	0.3011	3.750	24
20b	0.2955	0.2702	0.2722	0.3141	0.4671	0.5751	0.3076	0.3867	4
21a	0.5352	0.3769	0.3865	0.4665	0.5154	1.592	4.287	1.474	23
21d	0.5128	0.2983	0.3148	0.4970	1.392	626.1	10.63	127.8	25
22	0.4013	0.3218	0.3271	0.3850	0.4788	1.876	0.2920	0.6813	15
23	0.5181	0.3769	0.3856	0.4582	0.5140	2.362	0.3168	0.8290	19
24	0.2960	0.2399	0.2420	0.2593	0.4541	0.5511	0.2416	0.3604	3

Figure 4 shows the score of participants versus the ranking obtained in the competition, excluding that of the participant with the worst score for a better readability of the figure.

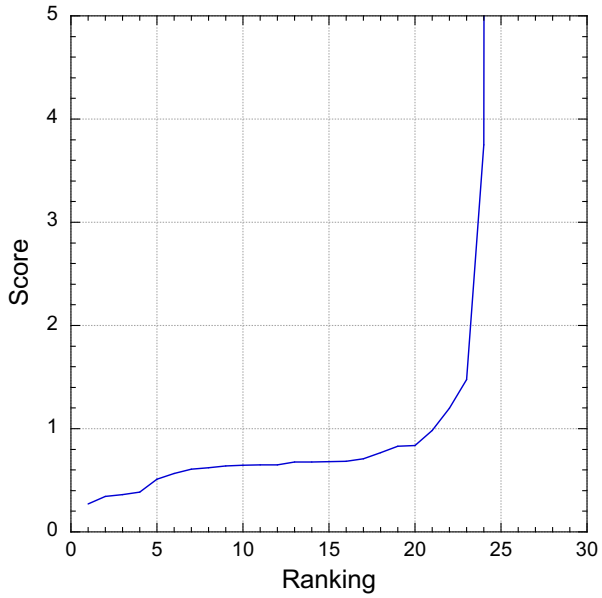

Figure 4. Score of participants

The best score, i.e., the minimum, is 0.2704, which corresponds to Participant 9, Lex van der Meer and Krishna Ajithkumar Pillai, from ABT bv, The Netherlands. Since the organization of this competition did not obtain explicit permission to publicly disclose the classification of now-winner participants by identifying their name (or the name of team's members) and corresponding affiliation, this has not been included in this document. The classification of the remaining participants was communicated individually by e-mail to the corresponding author.

30 October 2023

Joaquim Barros (Convener)

Beatriz Sanz (Deputy convener)