FINAL REPORT
WITH RECOMMENDATIONS

D1.4 Final report

WP1. Identification of similar curricula in the subject area

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Executive Summary

WP1 contained three deliverables.

The first deliverable was the investigation of Similar Postgraduate Study Programs in Asia. The task is divided in two parts

a) Desk research for similar postgraduate courses at universities in Asian countries.

b) Qualitative research through focus groups involving the main stakeholders, i.e. academicians, students and representatives from related industries.

The desk research was conducted without problems, but the implementation of the focus groups' meeting was hindered by the COVID19 pandemic. However, both tasks were successfully completed, yielding useful results on the current state of the CFD-related postgraduate programmes in the Asian region.

The second deliverable was the investigation of Similar Postgraduate Study Programs in Europe. The research was composed of two instruments:

a) Desk research for similar postgraduate courses at universities in Europe.

b) Qualitative research through questionnaires to academic experts in CFD.

The desk research was conducted without problems, but the online survey of the academic experts was difficult to complete due to the overwhelming of the academic community by the consequences of the COVID19 pandemic. The final results, however, were adequate and highlighted the important features and the best practises of a CFD-related MSc programme.

The third deliverable of the first work package WP1 was the investigation of similar VET programs in ASIA and specifically in the partner countries of Thailand India and Malaysia.

1. Review of CFD related programs in Asia

The first activity that was undertaken for the purposes of the 1st work package, was to identify similar programs in the Asian partner countries and in the wider region, in order to identify the gaps and better assess the exact academic needs of the institutes at hand. The methodology for this activity comprised of three instruments: **(i)** Mapping of programs in Higher Education Institutes, **(ii)** Creation of an inventory of MSc programs and **(iii)** Compilation of an inventory of courses. The critical evaluation of this data is aimed to ensure that the proposed Master Course, will not overlap with existing master courses and be truly innovative.

1.1. HEIs in partner and other Asian countries

This instrument involved a systematic review of the HEIs in the Asian partner countries and in the wider region. Concerning the former, it was found that India has a considerably larger pool of HEIs (11,718) compared to Thailand (148) and Malaysia (466), so it was unfeasible to conduct an exhaustive research of all the Indian institutions. Instead, a selection of the most highly accredited and popular institutions was used for the needs of our research. It was found that there are several types of HEIs in each country (public/government, private, autonomous, military, etc.) and among them, several that included engineering schools. In Malaysia and Thailand, the CFD-related subjects are covered mainly in the curricula of Mechanical Engineering Departments, while in India they are also covered in the curricula of Aerospace Engineering departments.

The other Asian countries that were researched, were chosen based on the educational capacity and they include China, Japan, South Korea, Singapore and Indonesia. However, there is a vast number of HEIs in these countries and in many cases, it was difficult to extract adequate data due to different educational systems, lack of translation in the provided information, etc. Hence, a selection of representative HEIs that offer CFD-related MSc programs was chosen for each country, specifically 3 in China, 3 in Japan, 3 in South Korea, 1 in Singapore and 1 Indonesia.

1.2. CFD-related MSc programs

The CFD-related MSc programs were examined to obtain insight into the structure of the curriculum, review the teaching methods and identify good practices that could be adopted in the APPLY program. A general division of the programs that were identified is between MSc by research and by coursework. Our review focused on the ones that involve coursework, which are relevant to the APPLY project. Most of the reviewed programs correspond to 35-45 ECTS units per semester. Each course corresponds to 3-6 ECTS units, depending on factors such as the lecture hours (typically 36-48 per semester), the type of the course (core/elective), lab exercises and training, etc. Almost all the programmes include a master thesis which corresponds to approximately 40 ECTS units, i.e. the workload of one semester. The total ECTS units of all the reviewed programs ranges from 150 to 200 units, but the duration varies between the different educational systems. A typical example is Japan, where the duration of a fulltime MSc program is 1.5 to 3 years, while for the part time option it can be extended to 3-5 years.

An important observation from our review is that only one Institution of the three Asian partner countries offers an explicit master on CFD. All the other programs include in their curricula CFD-related courses, placed in the wider framework of an MSc in Mechanical/Aerospace Engineering or Applied Mathematics.

In Thailand and Malaysia, the number of MSc programs that offer CFD-related courses are 18 and 5, respectively. In India, apart from UPES (standalone private university) that offers an explicit master in CFD, 14 other MSc programs were identified that include courses relevant to CFD, in the reviewed HEIs.

Concerning the other Asian countries, similar conclusions were reached, i.e. most of the CFD-related courses are offered in the context of MSc programs in mechanical engineering. One interesting approach was found in Singapore (NUS – National University of Singapore), where there is an option to follow a specific direction for the core courses (e.g. Applied Mechanics, Energy & Bio-Thermal Systems, Fluid Mechanics, Controls & Mechatronics, Materials, and Manufacturing) and specialize in Computation and Modelling. This structure creates a very diverse environment of specialization that includes many aspects of computational mechanics, offering a wide range of choices for the students.

1.3. CFD-related courses

A significant number of courses were reviewed in each of the three partner countries (153 in Thailand, 50 in Malaysia and 100 in India), to understand the current backdrop in the relevant MSc programs. The CFD-related courses that were reviewed can be divided into 4 different clusters, which are presented in Figure 1. *Computation and Numerical Modelling* covers 26% of the courses while *Fluid Mechanics*, *Energy* and *Special Topics* 23%, 24% and 27%, respectively. As we can see that each cluster does not dominate, but has almost similar share. This pie graph shows that physically CFD program not only does depend on computing/modelling, but also on solid fundamentals in Themofluids as well as applications, in order to complete each student's learning curve.

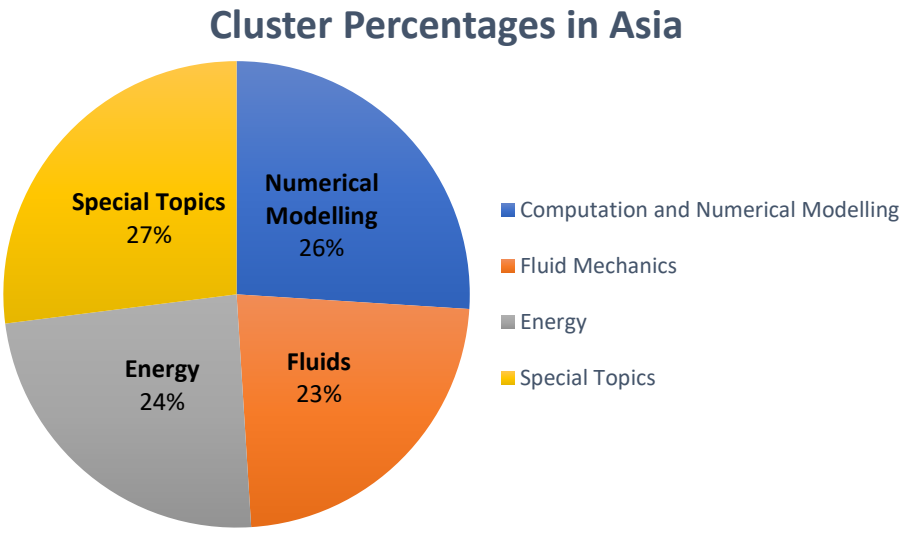

Figure 1: Percentage of each cluster of courses, in CFD-related MSc programs in Asia.

Most curricula require students to take courses in basic subjects such as Advanced Calculus, Fluid Mechanics and Transport Phenomena, in order to provide the same basis to all students, including those who do not hold bachelor's degrees in engineering. In some cases, two or three topics are combined in a single course, e.g. *Fluid Mechanics and Heat/Mass Transfer.*

Apart from the basic subjects, special topics are offered in each country and each HEI, depending on the specific needs of the country and the expertise of the academic staff. For example, Thai and Malaysian

universities offer advanced courses in refrigeration and air conditioning as they are tropical countries, and air conditioning and refrigeration are major industries. The special topics are also dependent on the inclusion of business-oriented direction in the curriculum, so quality management, technopreneurship and innovation courses are offered in some Malaysian HEIs.

Table 1 presents all available CFD-related courses in 8 Asian countries compared to those proposed by APPLY. India and China cover all APPLY courses except the elective course "Simulation in Buildings and Aerodynamics". However, this subject may be under Civil Engineering, which is beyond this study. The 2 APPLY courses in "Introduction to High Performance Computing" and "Hands-on Computational Fluid Dynamics" are not inscribed by most universities' curricula. Though these can be learned through research theses/projects, they are more structural in the curriculum. Therefore, the APPLY proposed program for MSc in CFD can be a good practice for Asian countries

Table 1: Comparison of courses available in Asia to the courses of the APPLY proposed program.

Type	APPLY Course	Thailand	Malaysia	India	China	Singapore	Japan	S. Korea	Indonesia
Core	Numerical Methods for Partial Differential Equations (PDEs)	✓	✓	✓	✓	✓	✓	✓	✓
	Introduction to High Performance Computing (HPC)	✓		✓	✓				
	Advanced Fluid Dynamics and Heat Transfer	✓	✓	✓	✓	✓	✓	✓	✓
	Advanced Heat and Mass Transfer	✓	✓	✓	✓	✓	✓	✓	✓
	Turbulence Modelling and Simulation	✓	✓	✓	✓	✓	✓	✓	✓
	Hands-on Computational Fluid Dynamics			✓	✓				
Elective	Computational Aerodynamics			✓	✓				
	Chemically Reacting Flows - Combustion	✓	✓	✓	✓	✓	✓	✓	✓
	Fluid Structure Interaction	✓	✓	✓	✓	✓	✓	✓	✓
	Linking Experiments with CFD			✓	✓				
	Environmental Flows			✓	✓	✓			
	Multiphase flows	✓	✓	✓	✓	✓	✓	✓	✓
	Modeling and Simulation of Energy Systems	✓	✓	✓	✓	✓	✓	✓	✓
	Simulation in Buildings and Urban Aerodynamics								

2. Focus groups

The organization of meetings between representatives of the main stakeholders (4 academics, 3 students and 3 representatives from related industry companies) was the second main composite of the effort to gather information on needs and gaps that must be addressed by APPLY partnership. This effort however was hindered by the effects of the COVID19 pandemic. The timing of this action coincided with the general lockdown, which was imposed in all three Asian partner countries, so the organization of meetings with physical presence was not possible. Finding and contacting the industry representatives was especially difficult, since most of the businesses were closed. The situation was discussed in two consecutive meetings of the APPLY consortium (10-Apr-2020 and 30-Apr-2020), where it was agreed that the focus groups could be organized separately for each involved group to facilitate the process. It was decided that the interview could be conducted via e-mail, phone, or by other means. For Malaysia, four academics, three students and three CFD-related industries responded to the Focus Group Discussion Questionnaire, while in Thailand five academics with variety of fields of expertise and backgrounds in CFD have responded to the questionnaires.

2.1. Academic experts

The discussion with the academic experts revealed that the unique selling points in terms of educational perspectives are (i) highly trained staff and links with research programs as well as research publications, (ii)

educational laboratories and (iii) part time courses. When considering types of students in their target groups, engineers were viewed the highest, followed by physicists, mechanics, mathematicians and software engineers/developers.

Concerning the technical skills, Programming and Mesh Creation were viewed by two respondents as important while one viewed as very important. On the other hand, all respondents viewed Commercial CFD Codes Usage as important. In addition, the importance of Commercial Software Packages was considered by average as scale 3 of 5

For learning organization, the most desirable mode of delivery in CFD-related post graduate programs is viewed via Projects followed by seminar, work experience and distance learning. Lectures in classroom is considered the least. Timing of delivery during office hours was viewed as the most desirable followed by weekends.

The gaps in the skill provision related to their CFD-related programs are Flow induced vibrations, Aerodynamics, Rotating flows, Multiphase flows, Micro/nano-scale flows, while the background of knowledge on fluid mechanics was viewed as highly important due to broad background of students including non-full time.

Some of those academics even kindly provided the missing skills in industrial viewpoint of the current CFD-related programs as listed below:

1.Career prospects of CFD specialists - most industry in Thailand normally rely on know-how or services from abroad. This also means the lack of collaboration of industry and universities.

2.The understanding of basics in fluid mechanics: the lack of ability in classification of fluid flow and understanding physics of the flow. The current lacking knowledge and skills in CFD related postgraduate programs are severe such as fundamentals in fluid mechanics both incompressible and compressible flow, linear and nonlinear problems including soft skills.

2.2. Industry experts

The industry stakeholders provided the important gaps in the current skills provision in the current MSc/Professional training courses offering for CFD such as knowledge of computer simulation using commercial software, technical skills in programming and software usage, soft skills and internship.

The needs and challenges in computer simulation the academics or the industrial are facing can be categorized into three areas as (1) facility and equipment (2) skills and (3) training course. It was identified that any activities or processes related to CFD required high cost and high-end equipment. The needs to purchase expensive commercial CFD software, which is constantly being upgraded, was a challenge. Skills and Training Courses in CFD are lacking.

2.3. Students

The expectations of the students are mainly relating to technical skill that included problem solving and application in CFD and inculcating attitude after attending a training programme. The characteristics of the graduates for the training course such communication and presentation skills ranked the highest followed by problem solving skills and creative skills.

3. Review of CFD related programs in Europe

An important element of the design process for the APPLY project is the review of the various formats of the existing MSc programs that are offered by EU HEIs. The examination of the corresponding curricula and the identification of the best practices are valuable input for the development of the APPLY MSc program. The key features that were compiled are the duration of each program, the total ECTS credits, the number and distribution of courses in each semester, the scientific areas of CFD that each program emphasizes in, the possibility of an industrial internship, whether or not a Master thesis is obligatory etc.

3.1. CFD-related MSc programs

The desk research identified 101 CFD-related MSc programs offered by 74 European HEIs. Most of these offer a degree in Mechanical Engineering, Thermal Engineering and Aeronautical/Aerospace engineering, which cumulatively correspond to 60% of the total MSc programs. The ones that are closer to the APPLY concept offer MSc degrees in Computational Mechanics (11%). The categorization of the MSc programs according to the scientific area can be seen in Fig. 2.

Most of the MSc programs correspond to 120 ECTS units and their duration is 4 semesters (typically 30 ECTS units per semester). However, there are also programs that last 2 or 3 semesters (60 or 90 ECTS units, respectively).

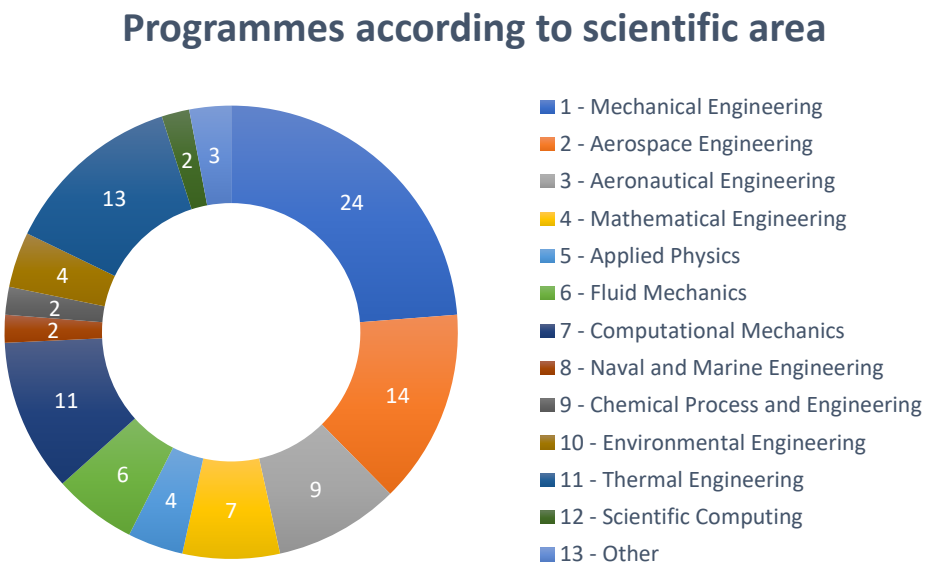

Figure 2: The distribution of master programs in the main scientific areas.

3.2. CFD-related courses

The preliminary design of the curriculum of the APPLY project involves 6 core and 8 elective courses, which can be categorized into four main categories – Energy, Aeronautics, Environment and Special Topics – as shown in Table II. To understand the links between the APPLY courses and the ones offered by the reviewed MSc programmes, the curricula of the relevant master programmes were analysed and categorized. The result is presented in Fig. 3Figure 3, where it is seen that 438 courses are similar to the APPLY core courses, 137 pertain to the Energy category, 58 to the Aeronautics category, 29 courses to the Environment category and 33 to the Special Topics category. 31 courses are unrelated to the suggested APPLY courses, dealing with subjects such as Physical Gas Dynamics, Space Propulsion, Modelling Re-Entry Flows, Plasma Physics, Methods and Models for Statistical Mechanics, Microsystems and Microfluidics etc.

Table 2: Categorization of the core and elective suggested courses of the APPLY program.

	Course Name	Grouping category
1	Numerical Methods for Partial Differential Equations (PDE's)	**Core** Courses
2	Introduction to High Performance Computing (HPC)	
3	Advanced Fluid Dynamics	
4	Advanced Heat and Mass Transfer	
5	Turbulence Modelling and Simulation	
6	Hands-on Computational Fluid Dynamics	
7	Aerodynamics	Elective Courses: **Aeronautics**
8	Fluid Structure Interaction (FSI)	
9	Chemically Reacting Flows – Combustion	Elective Courses: **Energy**
10	Modelling and Simulation of Energy Systems	
11	Environmental Flows	Elective Courses: **Environment**
12	Simulation in Buildings and Urban Aerodynamics	
13	Multiphase flows	Elective Courses: **Special Topics**
14	Linking Experiments with CFD	

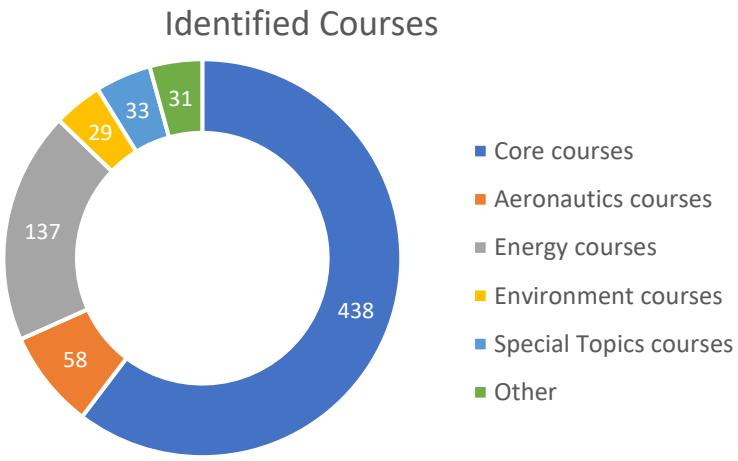

Figure 3: Distribution of the identified courses according to their type.

From the results of Fig. 3 it is evident that the courses that constitute the backbone of the APPLY MSc, are offered in a wide range of masters programs. They are essential in all of the main scientific areas that were reviewed in Fig. 2, i.e. Mechanical, Thermal and Aeronautical engineering and they are the main subject in Computational Mechanics.

These observations are highlighted in Fig. 4, which shows the distribution of the course categories with respect to above-mentioned scientific areas. The APPLY core courses correspond to 45-65% of the courses offered in Mechanical, Thermal and Aeronautical engineering masters and they are considered essential knowledge for all these engineering branches. The APPLY electives are the courses that define the specialization of each program and specifically, Mechanical and Thermal engineering programs give emphasis to courses related to energy (20% and 40%, respectively), while Aeronautical engineering programs include more courses on aeronautics (20%). As for the MSc programs that focus on Computational Mechanics, they are composed almost entirely (84.3%) of courses that are in the core of the APPLY curriculum.

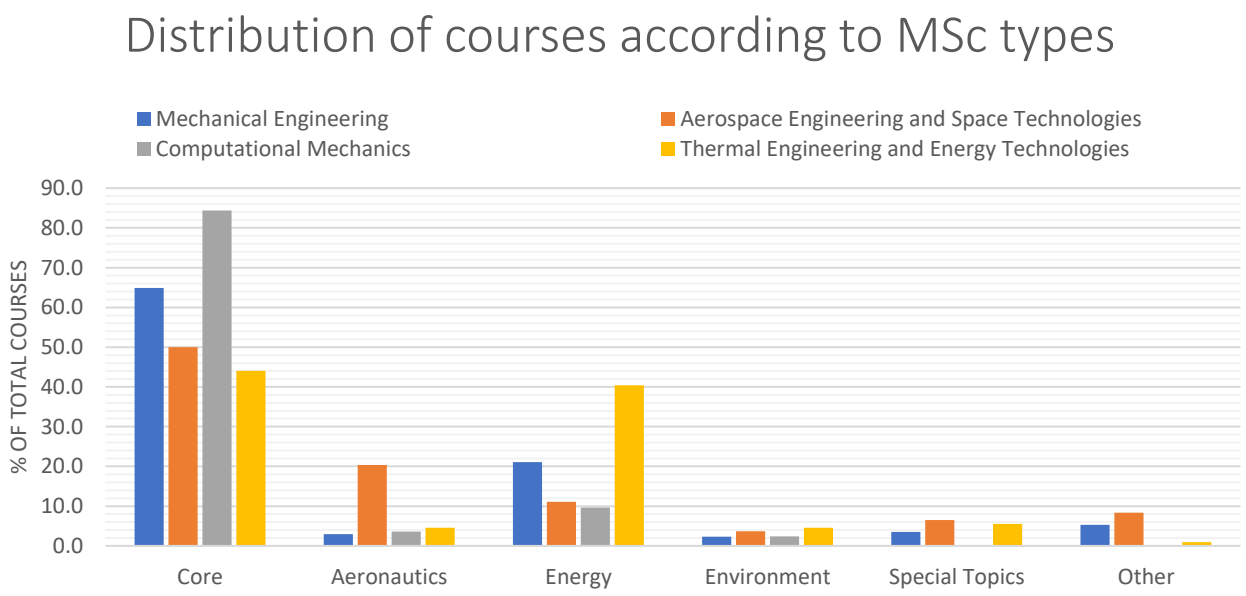

Figure 4: Distribution of courses in the four most popular MSc types of programs in European countries.

4. Questionnaires from EU Academic Experts

The second part of the research on the European HEIs, involved administering questionnaires to academic experts to get their input in what would be the ideal way to structure the MSc program and what best practices to include. A list of 335 academic expert was compiled from Institutions from 18 European countries and they were sent multiple invitations via e-mail, to participate in the online research. However, the period of our survey coincided with the peak of the COVID19 in most EU countries. Due to the disruption in the operation of HEIs throughout Europe and the limited availability of academic staff, only 45 responses were received. From personal communication with academic peers, it was understood that the reason for the reluctance to participate in the online survey was the massive shift to online academic operations (teaching, meetings, exams etc.) which flooded the accounts with emails and, combined with the pandemic, overwhelmed the academic staff.

However, the new situation with most of the academic operations being executed online, is indicative of a possible future direction for the implementation of MSc programs. The acquaintance of students and academic staff with online teaching tools, the travel restrictions and other consequences of the pandemic, which are expected to last for some years, as well as the nature of CFD, which can be practiced online (cloud computing, online tools, etc.), form an opportunity to explore new ways of implementing the MSc program. This involves adopting remote teaching methods whenever it is possible, utilizing online tools for assignments, exercises, labs, etc. and preparing the coursework to the direction of online studies. This possibility to implement a program oriented towards remote learning will be discussed in the next phase of the APPLY project, which involves the design of the MSc program.

4.1. Outcomes of the online survey

The questions of the online survey aimed at highlighting the relevance of the APPLY project with existing MSc programs, the features that are considered important by the academic experts and the best tools for implementing CFD. In many aspects, the results agree with the findings of the MSc programs' review that was presented in the previous section. Specifically, the participants confirmed that the course structure of the APPLY project has many similarities with the MSc programs in the European HEIs where they serve, thus confirming that design the APPLY curriculum is in pace with those of the European counterparts.

Concerning the business perspective of a CFD degree, it was found that all the traditional CFD-related subjects such as Aerospace, Automotive, Energy and Environment are considered important or very important. In addition, the potential of CFD in health-related applications was highlighted, while the relation to manufacturing was deemed less important. In the same context, most of the participants consider a CFD degree more appealing to the industry than a general computational mechanics course. This notion was the motivation behind the APPLY project, which aims to be CFD-oriented program.

The next set of questions attempted to resolve some matters that are important to CFD studies, such as the balance between teaching the fundamentals of CFD versus practical real life applications, the use in-house codes versus commercial CFD packages, and the placement of CFD in the context of computational mechanics and Multiphysics studies. The results showed that a balanced approach was the best choice in all the above questions, highlighting the need to balance the tradeoff between completeness in the offered knowledge and compactness in the courses design.

Specifically, it was found that equal weight should be given to fundamental CFD and real life applications and that there is no consensus over whether in-house coding is more important than commercial CFD, although they are both important components of CFD studies. The two main CFD tools that the students should be familiar with are OpenFOAM, which is open-source, and ANSYS Fluent, which is a commercial package. This result shows that the choice of the CFD tools depends on both the academic value, which is higher for open-source software where the student can work on the code, and commercial acceptance, as Fluent is used in many industries for R&D.

The academic experts agree that it is important to have a Multiphysics aspect in the MSc programme, which suggests that the curriculum should have diversity with respect to the offered subjects. Finally, most of the participants are in favor of or neutral to the proposition that CFD should always be part of a wider computational mechanics curriculum. This result shows that even if CFD is the core of the curriculum design, other subjects that are associated with computational mechanics should not be ignored.

The final set of questions aimed to highlight the features that the academic experts consider important assets of the masters offered in their institutions. From an academic perspective, the staff, the links with research/publications and the available facilities (labs, computing power), are the main competitive advantages that they mention. At operational level, one-year full time masters and low fees are considered important features of the programmes, while there is an underdevelopment in distant learning operations and e-class/moodle platforms. These gaps in the remote learning services, which are evident in the period of COVID19, and their consequences should be taken into account in the pending design of the APPLY programme structure.

5. Review of professional training courses in Asia

The investigation of professional/VET courses (where available) in the Asian HEIs in Malaysia, Thailand and India, was the final task of the first WP. In the following paragraphs, we summarize the main findings per country.

Malaysia

In the Country Report of Malaysia, there were a wide variety of VET courses offered by educational institutions, as well as governmental and vocational enterprises. Most of these programs were centred around new technologies and their applications in different fields. In the Focus Groups in Malaysia there are several challenges that face each of the fields included in the interviews

Thailand

In Thailand country report, it was found that curricula used in the country do not stimulate creativity, problem-solving, or prepare graduates for challenges of modern industries. This is because it is more theory-based than practical. Five government and private institutions were identified to be offering VET courses focused on CFD. In the Focus Groups in Thailand, few sectoral challenges were identified from the interview analyses.

Metrology sectorEnergy SectorManufacturing sector

Solid and fluid computational skills needed

Companies actively seeking data scientists as they seek to grow databases

Analysis and innovativeness are key skills

Design thinking, deep-basic, and simulation are demanded but in short supply

India

Several institutions, both private and public, were identified to be offering VET courses. The curricula fall short of meeting engineering market labour needs and should always be revised to meet modern industry challenges. Computational skills should also be prioritized in educational curricula because demand for them is rising. Demand for applications solving engineering problems will continue to be a phenomenon in industry.

6. Conclusions and Recommendations

The review of the postgraduate CFD-related programmes in Asia and Europe, and the feedback from the stakeholders and the academic experts have led to useful conclusions, which are summarized in the following points:

- Most of the reviewed programs in Asia correspond to the equivalent of 35-45 ECTS units per semester. Each course corresponds to 3-6 ECTS units, depending on factors such as the lecture hours, the type of the course (core/elective), lab exercises and training, etc. Almost all the programmes include a master thesis which corresponds to approximately 40 ECTS units. In EU HEIs the ECTS system ensures a unified approach, with 30 ECTS units per semester. Most of the MSc programs correspond to 120 ECTS, including a masters Thesis. However, many academic experts consider that programmes with 1-year duration are much preferable than longer ones.
- An explicit CFD master is offered in only one University in the three Asian partner countries, but there are several MSc programmes in Mechanical/Aerospace Engineering or Applied Mathematics that offer CFD-related courses. In European HEIs, the masters subjects are more diverse, but the main CFD-related programmes are in Mechanical Engineering, Thermal Engineering, Aeronautical/Aerospace engineering and Computational Mechanics.
- The review of the MSc programmes in the wider Asian region revealed an interesting approach in the National University of Singapore, where the students can select core courses that follow a specific direction (e.g. Applied Mechanics, Energy & Bio-Thermal Systems, Fluid Mechanics, Controls & Mechatronics, Materials, and Manufacturing) and then specialize in Computation and Modelling.
- Regarding the courses offered in the Asian CFD-related MSc programmes, four main clusters were identified, i.e. Computation and Numerical Modelling, Fluid Mechanics, Energy and Special Topics. Most curricula require students to take courses in basic subjects, to provide the same basis to all students, including those who do not hold bachelor's degrees in engineering. A few programmes offer courses about quality management, technopreneurship and innovation. In the EU region, the course categorization is similar to the APPLY programme structure, with a strong presence of core courses on CFD fundamentals and several electives that can be divided in four main categories, i.e. Energy, Aeronautics, Environment and Special Topics. According to the academic experts, equal weight should be given to fundamental CFD teaching and real life applications in the curriculum of the APPLY project, highlighting the need to balance the tradeoff between completeness in the offered knowledge and compactness in the courses' design.
- Concerning the specifics of the teaching material, the academic experts consider both in-house coding and familiarization with commercial CFD equally important. The two main CFD tools that the students should be familiar with are OpenFOAM and ANSYS Fluent. In this context, the labs and facilities of the host institute (software, computing power, etc) are considered important assets for the programme.
- The difficulties that were encountered in the completion of the first WP of the APPLY project due to the COVID19 pandemic, as well as the new reality that is being experienced in the European and Asian universities, highlights the need to keep an open mind towards remote learning methods and online teaching tools. The computational nature of CFD provides a great opportunity to utilize new technologies and incorporate tools like cloud computing in the teaching process.