ABSTRACT
This paper classifies and discusses recent practices of timetabling in higher education institutions in the western world. Timetabling is subjected to growing tensions. Not only budgets are being cut, the shift to sharing more of the same resources available has caused planning processes to adapt. This paper contributes by means of recognising those shifts. This includes results based on a systematic literature study in which differences and similarities in theory and practice of timetabling in higher education are described and discussed.

Keywords
Higher educational institutions, HEIs, timetabling, characteristics, algorithms, higher education.

1. INTRODUCTION
Nowadays, a paradigm shift is occurring in the field of education logistics. Higher education institutions, abbreviated as HEIs and referred to as universities and colleges of higher education, have to deal with an onset shift of centralising and diminishing resources like institutional locations and housing due to budget cuts. In most national systems, those budgets are tied to national expenditures, which are based on public policy.

The more traditional and conventional view of education is gradually transforming into a student-central hands-on learning platform where practices of rote learning are being less applied. Moreover, people are more likely to study overseas at other HEIs or participate in courses offered for distance education. Tools like e-learning and MOOCs emerge from educational technology and help to opt for those choices. Therefore, most HEIs tend to offer learning programs and courses which enable students to develop a new set of skills they can use to adapt to the demands of the changing world. Instead of following a fixed curriculum scheme, a modular approach is chosen in which various specialisation options are being offered.

Western HEIs, as stated above, are defined as HEIs in Europe and North-America. Within this research domain political, social, but above all, economic similarities are recognised.

Moreover, the extent of budgeting is different in comparison to other countries in other parts of the world. By recognising the social, political and economic challenges as stated, it is clear that students in the western world are demanding more flexibility from various facets in educational logistics. As a result, this trend pushes timetabling practices to the limit, which is the topic this paper focuses on.

The fact that timetabling has to adapt by means of aforementioned developments, is not only caused by increasing competition among western HEIs by offering students flexibility, but is also caused by declining budgets. In combination with the receding availability of (shared) resources, HEIs have to adapt their timetabling practices in order to maintain quality of studiability, suitable timetables for (support) staff and the degree of efficiency, whilst maintaining the educational quality levels.

When searching scientific literature databases one can notice that writings about timetabling practices in higher education are being published in increasing numbers in the last decade (2005-2015). Those writings include publications in the field of timetabling in higher education, practices and tools, timetabling algorithms, etc. Figure 1 reflects this trend when Google Scholar is accessed with searching terms “(Timetabling OR Timetable) AND Higher education”.

The increase of available and increasing amount of literature confirms that more research is being conducted in the field of educational logistics. As being aforementioned, available resources are decreasing and western HEIs are expected to adapt to a more flexible educational structure. How do HEIs cope with those changes and rising tensions? This paper designs a classification in which state-of-the-art timetabling in higher education is listed. We look at notable differences in approaches described in recent literature and real-life implementation, as subjects to be covered in this paper.

1.1 Problem Statement
Conducted research in timetabling in HEIs has advanced rapidly in which practices and theories have been developed and elaborated increasingly. However, giving rise to the problem that a lot of papers discuss situational topics based on environmental characteristics, it is important to identify, classify and differentiate between those characteristics and
developments for giving a state-of-the-art overview of timetabling in HEIs in the western world. Conducting a literature review enables us to investigate gaps between theory and practices of methods and processes used in this research domain. This review also helps us to orient on this field of research in order to provide insights for future research.

1.2 Research Questions

Based on aforementioned the following research questions are derived:

RQ: What is the current practice and theory of timetabling in higher education institutions (HEIs) in the western world?

Planning processes can be divided by means of the resource type. Personnel-, product-, educational-, or locational planning are examples which have an effect on planning processes. The research domain of this paper is limited to higher education institutions in the western world, as explained in the introduction section.

Now that the research question has been formulated, it is notable that some parts need further elaboration. Hence, underlying the formulation of the listed sub-questions for specifying the main question:

1) What are developments in timetabling?
Timetabling consists of a set of operations. A classification of this in terms and processes is needed in order to give a clear definition of research boundaries.

2) What are characteristics of HEIs?
3) How do the two combine, giving us the overview we are looking for?

2. METHOD OF RESEARCH

Based on the research questions formulated in Section 1.2, this research demands a qualitative design approach because of the explanatory nature of the research questions. Besides this, the increase in the output of research publications in the field of timetabling has led to the fact that it is more difficult to keep track of what work has been established of the various aspects within this field.

A good literature review takes the following elements into account: state of the art – current, the research problem covers the topic which is focused on – relevance, identifying evidence, trends and conclusion in relevant studies - thorough, gaps in research and inconsistency in findings and areas of further research are pointed out – critical [42]. In order to satisfy those characteristics, the 5-step method of Khan et al. [51] is used. This process includes: 1) question framing 2) identifying relevant literature/publications 3) appraising quality and methodology of those studies 4) summarising the evidence, and subsequently 5) interpreting the findings. Question framing and data retrieval are steps that are briefly discussed.

2.1 Question Framing

Within framing the question, the relations between the components of the problem question have to be established and displayed. This lays the foundation for the structure of the research. Figure 2 shows those relations:

![Figure 2. Research plan.](image)

Elaboration on figure 2:

- Timetabling in HEIs consists of listing developments in timetabling (1), in combination with the operational and structural characteristics of HEIs (2).
- Developments in timetabling (1) encompasses the one hand research in timetabling domains (3), and on the other hand trends and developments (4). Trends and developments is subsequently explained by means of timetabling software application developments (5) and timetabling algorithm developments (6).
- Characteristics of HEIs (2) emerges by describing HEIs governance (7), HEIs structures (8) and trends and developments of HEIs (9).
- The combination of the components (1) and (2) outlines an initial view on state-of-the-art timetabling within HEIs and in which gaps between theory and practice are identified (10).

2.2 Data Retrieval

A long-list containing all papers which are relevant for this research can be generated based on reading the abstract, introduction and conclusion, while tracking why papers are rejected because of the validation and consistency for the review. In order to operationalise this search strategy a predefined method called PRISMA is adapted. PRISMA [61] consists of a four phase method in which critical reports are identified and included for synthesis. Below, these phases are applied for this research and explained in further detail.

1. Identification

Search terms used were formulated as follows: “Higher education AND (timetabling OR timetable). In addition, results published after 2011 are considered relevant. This research focuses on current practices and theory on timetabling, hence excluding literature older than 4 years. However, this obviously doesn’t apply for certain components of the research plan. It is justifiable that literature results from an earlier time period can be used alongside the 4-5 year criteria set. We keep track of records identified per database. Subsequently, duplicates will be removed and the result is a disjunctive long list of potential literature.

2. Screening

The number of excluded papers is recorded and provided with a brief explanation why those results have been excluded.

3. Eligibility

In this phase full-text is assessed in order to analyse introductions, subheads and conclusion/ discussion. Inclusion criteria applied are: 1) The paper addresses at least 3 developments of timetabling in HEIs, 2) The paper describes recent developments (< 10 years). As discussed in phase 2 screening, exclusions must be provided with a short reason.
4. Included
This is the final phase of this methodology, although retrieval has been rounded up at the end of phase 3.

3. DEVELOPMENTS IN TIMETABLING
This chapter aims to describe developments in solving timetabling optimisation problems. First, the timetabling problem is explained in further detail to give a clear understanding of a lacking general solution for this. The second section of this chapter outlines the advancements of automated timetabling throughout the years. Finally, a comprehensive view of several ways to solve timetable problems is outlined.

3.1 The timetabling problem
The constantly moving research field of timetabling has caused rapid developments in theory and practice. Wren (1996) [87] defined timetabling as: “The allocation of given resources to specific objects being placed in space time, in such way as to satisfy as nearly as possible a set of desirable objectives, subjected to constraints.” The presence of knowledge for creating timetabling software has led to new insights, like improved methodologies and more comprehensive models [57]. Besides this, an increased effectiveness of the timetabling process is notable. Appropriate resources are to a greater extent linked to needs of users as well as staff and student. Moreover, those developments encouraged new approaches for space utilisation strategies and interactive timetabling [11, 16].

Timetabling applications are nowadays capable of applying new techniques and solution algorithms for timetabling. Techniques and algorithms are taking more and various factors into account like performance issues, constraint requirements and student/personnel interests.

However, the variety of constraints, the diversity of the problem and specific requirements have caused finding an effective and general solution in timetabling to become more difficult [47]. There are different kinds of scheduling problems and timetabling is stated to be a common problem in this area. The timetabling problem is a so-called NP-hard and NP-complete optimisation problem, depending on the constraints [75]. Feasible, efficient or fast solutions are all synonyms for polynomial time. Yet, none of these solutions apply to the field of timetabling, which means that most of the timetabling challenges are not solvable within a realistic time frame. For these kinds of problems, computational heuristics are often taken into account as a solving strategy, resulting in a non-optimal but feasible solution [45]. Despite the amount of literature and research dedicated to this problem, a gap still exists between reality and models used, or, in other words, between theory and practice. This is discussed by McCollum (2006) [57], who identified that it is extremely difficult to find a generally applicable model whereas different institutions recognise different constraints. Many studies that attempt to propose a model use specific datasets for proving their solution or model [44, 77, 87], which to a certain extent excludes generalisability. However, in order to propose an institution-wide timetable a comprehensive formulation of the problem has to be made in which the problem is relevant to real world practices. McCollum emphasises that solutions for this problem must address a wider range of these practices rather than fine-tuning algorithms or meta-heuristics on particular datasets used.

3.2 Research in timetabling domains
Timetabling covers a variety of areas in which a significant amount of research has been conducted. Those broad domains encompass mostly educational, transport, employee, sports and healthcare scheduling and rostering. Within educational timetabling, school timetabling and university timetabling for courses and examination are most studied. However, research in the area of school timetabling has not advanced as rapidly as university examination and course timetabling [64]. This is due to the fact that studies are done in specific schools, in isolation [76], in contrast to university examination and course timetabling where more methods are compared for a set of problems or constraints instead of a study for a single institution.

A significant amount of surveys on educational timetables have been conducted in the past 10 years, see figure 1. This also includes literature presented at conferences that are dedicated to timetabling practices: Practice and Theory of Automated Timetabling (PATAT) and Multidisciplinary International Scheduling Conference: Theory & Application (MISTA), held every two years. One of the areas of their research covers methodologies for specific domains of timetabling. Those methodologies aim to solve, but rather optimise, timetabling problems, as explained in section 3.1. The construction of the solutions depends on how the timetabling problem is defined. The problem describes constraints variances and requirements and thus may alter from institution to institution. In recent studies, researchers use standardised formulations of those problems. Bellio (2014) [12] describes the most used variants in the education domain of timetabling. The problem is translated into a specific benchmark set and methodologies. Solutions and models are evaluated on those sets. Hence, researchers aim to evaluate their solution on multiple datasets in order to test for generalisation rather than specification, which is in line with what McCollum advocates.

3.3 Trends and developments
A notable amount of developments regarding timetabling systems and algorithms can be found in studies, surveys and literature. This paragraph aims to outline those developments, while taking the delineation of the research domain, as discussed in the introduction, into account. Subjects covered in this paragraph elaborate on the developments described in the preceding paragraphs in order to classify them.

3.3.1 Timetabling application developments
Timetabling problems and methodologies can be complex, iterative and time consuming. Timetabling developers increasingly adopt a computer-based approach which enables institutions to automate tasks, finding (sub-)optimal solutions and work more efficiently. This section aims to outline and review relevant studies conducted throughout the last decades. The decision to distinguish among decades is based on renowned surveys, conducted in the corresponding periods. Moreover, this is backed by the want to maintain overview and the possibility to describe developments in better details. In this section timetabling applications are defined as the set of resources which function in a computerised environment to enhance timetabling practices.

Up to 1980
One of the first applications on a computer was developed by Gunzenhäuser and Junginger (1964) [44]. They tested an algorithm combined with simple heuristics on a mainframe computer. However, the resulting timetable was not optimal
and needed modification by hand. In 1980, Schmidt and Strohlein (1980) [78] provided an annotated bibliography in which early techniques and system implementations were discussed. Most of these systems were based on graph colouring and recursive exchange operations in which partial timetables were extended.

1981-1990
The application of computational timetabling was still not widely accepted in the mid 80’s. Most of the institutions did not have microcomputers available and the ruling thought about being scheduled by a machine caused resistance [78]. De Werra (1985) [85] proposed graph, network and mathematical methods and how they could be used in timetabling programs of application. This study showed that certain requirements were not yet translated into constraints and included as ingredients in the various models. Ferland et al. [41] proposed a 0-1 mathematical model and implemented it on a microcomputer. The constraints, however, had to be relaxed because the computer was lacking memory space and computational power. Junginger (1986) [49] described various software applications implemented and elaborated on the underlying approaches, which were mostly based on direct heuristics. The research conducted by Junginger (1986) concerned institutions in Germany, however, the techniques and tools discussed were of a state-of-the-art nature by then. Remarkably, literature in this area in the period of 1970-1985 consists mainly of case studies which report specific examples of computerised registration (Sabin & Winter, 1986). This combination of case studies performed and the changing requirements of different institutions, made it difficult to produce standard computerised solutions. In the ensuing period of early 1985, a significant amount of institutions started to adopt the use of PC’s and were able to use big data entries [62].

1991-2000
A study of Bardadym (1996) [11] pointed out various aspects of interactive timetabling for timetabling software. Bardadym (1996) elucidated that timetabling software is capable of the following: database corrections, use of spreadsheets and DBMS, using timetabling editors and making use of an object-based interface. The use of those features, however, is mostly restricted to prove timetables’ correctness. The use of metaheuristics and interactive timetabling were seen as the new wave of computer-aided timetabling. Schaerf (1999) [77] illustrates this trend in a survey of automated timetabling in which the papers in this survey describe to a certain extent the implementation of timetabling software. The survey illustrated how modern heuristics, like evolutionary algorithms, seemed to outperform the traditional operational research methods. Institutions were now able to generate feasible timetables in an acceptable timeframe. However, there were still many cases in which the problem was computationally too hard. Moreover, Schaerf [77] argued the need for widely accepted benchmarks and a common formulation of the various timetabling problems. The absence of those elements caused that algorithms and software application programs could not be compared among each other. A significant number of software applications developed within this period was either a commercial product which meant it had lost the emphasis on algorithms and focused merely on the GUI, or it had been designed for a specific institution [57].

2000 - 2015
Recent state-of-the-art papers pay attention to problems and challenges featured in work over the last decades. More standardised benchmark datasets become available and researchers explore directions in which the timetabling problem is placed in a real world problem context [54,66]. Standardisation of timetabling benchmarks however, leads to circumstances in which practical real world application is not maintainable most of the time. In other words, benchmark sets are mainly generated by means of a standard set of constraints or constraints based on specific HEI characteristics. In both cases testing algorithms against each other is not feasible because of the lacking generally applicability of real world problems [57].

De Causmaecker et al. (2002) [25] discuss how the semantic web and components like XML, can be used in timetabling applications. In a study of Chand (2005) [26] the adaptation of relational databases and the modelling of timetabling data is reviewed. Ranson & Ahmadi (2007) [73] reviewed the limitations of existing timetabling languages and standards and proposed a modern flexible language-independent timetabling model which can be adopted in timetabling applications. It becomes clear that timetabling applications are provided with most modern tools, technologies and techniques [71]. However, a study conducted by Pillay (2013) [68] discussed that there still exists a gap between academia and industry. While academia tend to develop intelligent and profound methods to solve timetabling problems, industry appears to develop and design an easy to use interactive tool that aims to meet the needs of teaching and administration staff. Bridging this gap will produce robust, efficient and to a certain extent general, timetabling applications in which the most modern heuristic approaches for timetabling problems are combined with the benefits of an easy to use timetabling application.

3.3.2 Algorithms in timetabling, a short chronology
In this section, solutions to solve timetabling problems are discussed. These solutions are differentiated among various fields of heuristic optimisation algorithms [80]. Based on literature, a profound chronology of metaheuristics is provided and is briefly elaborated on. However, these fields are not mutually exclusive. A notable amount of metaheuristics algorithms combines ideas from these different fields. These kinds of methods are called hyper-heuristics. The aim is to provide different ways of finding solutions for the timetabling problem discussed. Analysing the various algorithms in greater depths, however, does not encompass the scope of this research. The chronology consists of a trichotomy. It is about grouping and declaring similar events occurred in such period.

Up to 1995
Welsh and Powel represented graph colouring strategies for solving timetabling problems. They built the foundation for more sophisticated research on graph heuristics in timetabling [59]. Graph colouring timetabling heuristics are constructive methods in which the construct is evaluated on and being improved.

Linear and integer programming techniques are mathematical based algorithms and assign integral values to variables. Variations of this technique were, and still are, a widely used method to solve combinatorial optimisation problems.

Constraint based techniques originate from research on artificial intelligence [15]. These techniques encompass constraint logic programming and constraint satisfaction techniques. However, such techniques are generally computer extensive by means of increasingly exponential amount of variables. In more recent literature, constraint based techniques are integrated with different heuristics and techniques in order to keep up with other state-of-the-art techniques.

1995-2010
In the late 90’s, methodological approaches for solving timetabling problems were in general being classified into two
categories of meta-heuristics: population-based approach and a single-based approach [22]. Starting with many candidate solutions, a population-based approach aims to find the best solution in the search space. The solutions are refined in a parallel optimisation environment. A single-based approach works with a single solution and then tries to improve for a better result. The constraints are satisfied in an iterative manner.

Local search: Tabu search falls under local search methodologies and is based on steepest descent search and tends to explore the search space by not re-interpreting recent moves. There are several important papers which carried out a valuable investigation of tabu search techniques [35,65]: (1) Diversification of the neighbourhood whereby the search is extended to find more local optima and (2) Intensification of steps made in tabu search algorithms to find faster solutions. Simulated annealing (SA) is another local search technique. This technique aims to search for a wider area of search space in which worse steps are accepted and allows for a more extensive search for the optimal solution. SA encompasses a certain amount of variant [22,39] but is often combined with hill climbing techniques [71] and constraint programming [15].

In line with local search based techniques, a recent trend recognises the definition of more different neighbourhoods. Structures like variable neighbourhood search [17] and large-scale neighbourhood [60] search are associated with such techniques.

In the subdivision of population based algorithms, evolutionary algorithms encompass a major set of population based techniques. Genetic algorithms are most common and studied among the evolutionary algorithms. Corne et al. (1994) [33], conducted a research on the use of genetic algorithms in educational timetabling and provided a survey on this. Such algorithms are based on best individual solution in the population space and each best solution provides the basis for a new evolutionary cycle [31]. A survey of Burke et al. (2009) [71] discusses different kinds of applications of genetic algorithms and how these algorithms are modelled. Memetic algorithms [21] is an addition of genetic algorithms. Memetic algorithms are mostly supported by local search methods and have the ability to explore a region of population based method with local search techniques. It is, however, challenging to find a right balance between exploitation of local search and exploration by means of population based methods of the search space. Alkan et al., [5] elaborated in their study on the use of memetic algorithm in timetabling. They acknowledge the need to keep a diversified population in order to maintain a right balance of the search space, as mentioned before.

Another population based technique which is researched on in greater depths for the last decade is the group of ant algorithms [37]. These algorithms keep track of information gathered during a search, subsequently, this information is used for generating new solutions in next stages [71].

**Recent**

However, both single- and population based approaches have their drawbacks. The main drawback of single-based approach is that the main focus lies on exploitation rather than exploration. This means that the search space is limited to one trend or solution for the current situation. Other solutions, however, are not considered. On the other hand, population based algorithms often experience premature convergence because of the lack of concentration on current solutions in the search space. Local optima in this search space are made progressively similar to each other, causing a loss of diversity. Lately, most timetabling researchers have focused on local (single) based solutions rather than populated based algorithms [4]. A development that emanated from standard local and population based solution for timetabling problems is the application of hyper-heuristics. Hyper-heuristics, in contrast to meta-heuristics, are searching for solutions in the heuristic space instead of the “plain” solution space. In other words, hyper heuristics is a search method in which several heuristics are combined and adapted. The difference between metaheuristics and hyper-heuristics is that hyper-heuristics seek to find a generally applicable methodology instead of solving a particular problem instance.

**4. CHARACTERISTICS OF HEIS**

HEIs are under growing pressure to deliver a student-central academic climate in which timetabling practices are fuelled by individual preferences [32]. Literature covering timetabling developments alone is not sufficient for satisfying those demands. The operational process of timetabling is embedded in specific institutions and must therefore connect to structural preferences held by these institutions. This results in HEIs influencing the way timetabling applications are adopted by means of their characteristics. Defining these characteristics of HEIs, in turn, is interrelated with (cross-)national ideologies and legislations which origins can be found in governmental influences and national systems of higher education (HE) [28]. In order to research the gap between theory and practice in greater depths, literature is reviewed concerning characteristics like knowledge levels, shared values and goals, organisational structure and current trends of governance in HEIs.

**4.1 Governance of HEIs**

Higher education encompasses a process of creating knowledge for enhancing employability and stimulating innovation whereby learning opportunities are made available through various institutions. HEIs are mostly integrated in a dynamic environment which is controlled and regulated by social, political, economic and institutional aspects (Scott, 2001). This regulation is translated in governance and describes to a certain extent how an HEI is organised and managed. Investigating HE governance supports the search to identify characteristics of HEIs because governance is always present in a HEI [55]. Governance embraces the determination of values inside HEIs, resource allocation and missions. The identity and formed culture of each HEI is shaped by legislations of HE governance. Nonetheless, the extensive notion of governance makes it difficult to categorise the structure of various systems in which HEIs are incorporated. Besides this, practices of HE systems and HE governance are
still predominantly shaped at national level [6]. A significant amount of research has been dedicated to national and cross-national analysis of HE systems and HEIs, explaining trends and characteristics [2,79]. Rising competitive pressures, demographic and economic developments as effects of globalisation and internationalisation stimulated HE governance to reform [36]. A study conducted by Dobbins et al. (2011) [36], proposed three ideal-type models of HE governance in which contemporary policy developments are reflected in: (1) in the state-centred model, HEIs are seen as state operated institutions. The state is heavily influencing internal matters like HEIs-business relations, quality assurance and efficiency. Education and research ought to contribute to industrial and technological competitiveness. (2) HEIs as a self-governing community is a model based on strong state-university partnership that is governed by assumptions of corporatism and collective agreement. (3) The third model is of a market-oriented nature. HEIs are seen as economic enterprises in local or global markets [55] and offer academic services to students. The aim is to bolster the choice of students in order to enhance quality and diversity of services offered. It is argued that those types are hybridised with each other in various countries.

4.2 Structure of HEIs
In the early 1960’s, most European countries placed emphasis on diversification of HE systems. Structures like binary(two)-type and multi-type were more likely to emerge. Those systems had to function as multipurpose, specialised HE. However, some countries continued to use a unitary system in which, for example, universities were the only kind of institutional type [28]. In the late 1970’s HE systems were increasingly paying attention to informal structural aspects like, quality assurance, excellence, job prosperity of graduates and reputation of the institution itselfs. In the ensuing period, as of the late 1980’s, the different kinds of institutional types of HE and diversification in programmes were no longer that relevant [34]. However, the occurrence of multi-type structures was likely to persist in various countries [3,14]. A study conducted by Teichler (2006) [83] discussed why a vast amount of changes in structural developments in HE systems were notable: this has been explained by a number of conceptual frameworks. (1) The expansion and diversification of HE systems lead to a more diverse need of students, moreover, he described an (2) “academic drift” of institutions in order to stabilise themselves and increase status. Finally, he identified a (3) cyclical trend caused by reoccurring events like dropouts, for example. As a result of this cyclical trend, diversification among HEIs is reduced or either different HE types are subjected to segmentation.

Around the late 1990’s, the tendency arose to make HE systems more similar across Europe. The Bologna process, proposed in 1999, tends to harmonise HE systems throughout Europe in order to ensure compatible degree structures, equal academic qualifications and enhancing the attractiveness of foreign students to study in Europe [8]. Those developments have to foster for structural convergent of HE systems in Europe. Making a more generalised view of characteristics in HEIs, which are embedded in HE systems, more admissible. While various aspects proposed in the Bologna process already have been implemented, there still is not a wide framework on a structural level for HE systems which makes up for exceptions.

4.3 Nationalisation and Globalisation of HE
Altbach (2015) [6] elaborates in his study on the commodification of HE. He identifies a trend in which HE is increasingly seen as a commodity, which can be purchased by a consumer in order to build a “skill set”. This skill set can be used in the marketplace and can be bought from HEIs. Commodification of HE implicates the marketing of knowledge products like, advanced training and bolstering of a highly skilled workforce. Two aspects which are interrelated with this are globalisation and internationalisation. Internationalisation of HEIs is mainly focused on fostering global learning experience, attracting overseas students and delivering national programmes abroad. This approach allows for situations in which the time and place dimension is merely less dependent whereas the focus on mobility is becoming more important in the learning process. Countries from all over the world move towards the internationalisation of HE. Such countries are opening their doors for foreign universities and programmes, are regulating foreign providers, are marketing national educational products and countries in Europe are harmonising their divergent HE systems as an implication of the Bologna process. Internationalisation and globalisation are intertwined [82]. Globalisation of HE embraces the more advanced information and communication technology, the emergence of a world-wide knowledge network as well as other influences beyond the control of HEIs [9]. In recent literature, HEIs are adapting newer IT practices to a greater extent [86]. Through the use of internet, programs can be offered at foreign universities. As IT become more sophisticated, distant learning or blended learning is becoming more wide spread (in combination with traditional learning). Blended learning is defined as the combination of traditional face-to-face education and technology mediated instruction [70]. A significant amount of research has been dedicated to the adoption and implementation of blended learning practices. Through the adoption of blended learning, students from different courses can participate in particular blended learning classes. It thus addresses some logistics changes that strengthens the need for a more flexible timetabling process. Another distant learning aspect is the rising topic on Massive Online Open Courses (MOOCs). They can be seen as scalable offerings of online courses which extend existing online learning approaches [88]. MOOCs have the possibility for freeing resources for HEIs in order to reduce costs and enhance space optimisation strategies, because participants are not bound to any location. Conclusions based on recent literature reflect that the emergence of MOOCs also accounts for structural changes and challenges in HEIs. Such kind of challenges in the field of timetabling in which questions like time-zone- and (fraudulent-free) examination planning arise. Concluding, MOOCs influence to a certain extent the allocation of resources, which encompasses timetabling practices.

4.4 Recent developments in HEIs
More and more external influences shape the policy, goals and characteristics of HEIs. The emergence of global rankings among HEIs is seen as a powerful stimulus for competitive thrive. HEIs are being constantly compared in a national and international context [46]. Even more in the setting of national competition: this global referencing caused that the institutional identity of the individual HEIs is becoming less important than the national identity of HEIs [82]. This is in accordance with the study of Teichler (2006) [83]: most institutions aim to stabilise themselves and tend to attain a higher status by comparing themselves to the most successful HEIs based on such rankings. Comparison in this manner caused many institutions making changes in policy and strategy, which is driven by the norm promoted by ranking.
Students associate those global rankings with education quality and opportunities for a career. So it is evident that students are playing a key part in these policy decisions. The student-as-consumer model has become increasingly prevalent contemporary. Many HEIs have begun to adopt customer-based models for students [30,32]. Emergence of marketing plans, marketing promotions by institutions and assessing students’ experiences as effectiveness of HE, are examples of such models. Seeing students as customers of HE encompasses societal needs and norms. Moreover, expectations of the labour market also influence the student-customer-based model, because it is indirectly related to the societal needs incorporated by students. In addition, student-teacher partnership collaboration is increasingly elaborated on in the last decade. This collaboration defines, and tries to understand, the role of both student and teacher in student learning [32]. Within this partnership, insights with reference to this relation student-teacher are collected. Furthermore, collaborations also aim to study and design teaching and learning together. Hence, this trend makes up for certain changes in structures and planning processes, like timetabling, in HEIs. To foster such developments in a more demand driven education structure, a flexible process of planning is essential. In this sense, the partnership must be harmonised in order to support a flexible environment between students and the HEIs. Direct implications are smaller-scale education, a shorter learning circle and more teacher FTEs [74].

5. TIMETABLING IN HEIs

5.1 Dynamic environment of HEIs

HEIs are in the last several decades subjected to both external and internal influences. This caused that particular HEIs are performing different roles. They are expected to meet demands from local, national and global pressures and ought to perform applied research, working with public sectors, local communities and having intertwined relationships with businesses [54]. Both government and society are setting demands for HEIs and there is in available literature a growing competition noticeable between individual HEIs [6,36,79]. Hence, those institutions have to cope with such external forces, but above all, fulfilling the students’ expectations. The lecture aspect of HE in the institutions is steadily evolving from a traditional teacher-centred didactic style to a more interactive-centred style [29]. On the other hand, personal developments of students are fostered in a short-cyclic and smaller scale educational setting. Nevertheless, it is utmost evident that the process of efficiently allocating resources in HEIs is in a constant moving field. Timetabling in HE has to deal with ever decreasing resources and is focused on delivering a feasible set of solutions in which the amount of variables, representing real-world applications, is constantly rising too [1].

5.2 Timetabling applications

Researchers in the field of HE timetabling acknowledge that timetabling solutions are diverse and institution-specific. The literature review conducted on characteristics of HEIs confirms and illustrates those diversifications between institutions. From the early 1960’s on, an increasing amount of timetabling applications and algorithms for HE have been developed in order to bolster the dynamic environment of HEIs in which those aspects are being implemented [85]. Within this period, different meta-, hybrid- and hyper-algorithms are modelled and proposed in papers aiming to be more generally applicable than most implementations [18]. As a result, the amount of papers steadily rose in which feasible automated timetabling solutions are proposed. This eventually led to a burgeoning focus on checking reliability of results claimed in papers on a benchmark application. Therefore, more online solving facilities emerged that encompass multiple instances of real-world problems of timetabling in HEIs. Researchers are nowadays capable of generally checking their solutions due to more enhanced and comprehensive benchmark sets. This is in favour of the design of automated timetables and eases the process of fine tuning algorithms of multiple heuristics to solve hard search problems. Furthermore, we identify that a wide scale of heuristic algorithms for timetabling problems already laid important groundwork: an increasing number of state-of-the-art research builds on this and aims to find the most suitable methods or sequence of heuristic algorithms to account for specific timetabling problems rather than finding solutions for the search problem self [20,50].

5.3 Timetabling at HEIs

In the last several years research aimed for a more enhanced and comprehensive search for optimisation solutions. Educational models are dynamic and subjected to change. Recently, a shift from a traditional to an interactive approach in which a demand driven model is more prevalent. This led to many researchers from all over the world developing timetabling software, but a vast amount of papers that were written about the software had their criticism on the fact that a standard benchmark instance was still lacking [12,23,77]. This paper shows, however, that a world-covering benchmark is not yet feasible. There are too many requirements and constraints that have to be taken into account, because many HE systems are still implemented on national level. There are aspiring ideas that are fostering for convergence of HE systems by means of the Bologna process, for example. This does not imply that a general applicable timetabling solution or software application is not attainable in the near future. The emergent research that aims to search for the most suitable methods in order to optimise timetabling problems is predominantly found in the field of hyper-heuristics. Based on the conducted literature review, it remains questionable whether contemporary state-of-the-art optimisation solutions are already being used in timetabling applications in HEIs. Furthermore, it is remarkable that researchers are following a substantially equal pattern regarding the developments of timetabling solutions in HEIs. The literature acknowledges various timetabling problems and proposes a new or enhanced model to cope with it. This model is explained and justified. Subsequently, the researchers test their proposal against several benchmark instances and discuss limitations. The actual implementation of these models in software applications, however, is often not described. In accordance with the study of Pillay (2013) [68] as described in section 3.3.1 timetabling applications developments, there still exists a gap between research and industry. To what extent do timetabling applications implemented in HEIs catch up with newer timetabling solutions in order to fulfil the demands of a particular HE system? The ensuing section is dedicated to conclude on this.

6. CONCLUSIONS AND DISCUSSION

This research provided firstly a review on timetabling developments. We subdivided trends and developments of timetabling in (1) timetabling application developments and (2) timetabling algorithm developments. A lot of research has been conducted in those fields and this resulted in an increase of
more advanced algorithms for timetabling solutions. This is illustrated by means of particular timeslots in a chronology. Over time, this paper identified, the most state-of-the-art algorithms have focused on selecting most suitable methods in order to provide for the optimal solution, rather than hybridising new algorithms. A considerable amount of papers identified the need for a standardised benchmark that covers multi-instances in order to test such advancements in optimisation solutions.

In the first part of the review on characteristics of HEIs we analysed literature about regulations and the way HEIs are being organised and managed. Institutions in HE are subjected to external influences and pressures of the environment and this illustrates that HE systems are still predominantly shaped at national level. Furthermore, the rising competitive pressures in HE caused changes in the field of the provision of services and the process of planning. The last decades the tendency arose to converge different HE systems in which composing a more general applicable timetable solution would become more admissible. However, it is evident that there are still various mutual differences among HEIs.

Literature illustrated to what extent practices of nationalisation and globalisation affect timetabling in HEIs. More sophisticated communication technologies enhanced the use of blended learning practices and the adoption of MOOCs, which resulted in freeing up resources and different space utilisation approaches for HEIs. Finally, the review encompassed identification of recent developments in HEIs. This paper identified that timetabling applications must offer flexible services to a greater extent. This is due to the emergence of global rankings, a prevailing student-as-consumer model and a dynamic demand-driven environment which implicated smaller-scale education in HEIs.

Combining research on developments in timetabling and characteristics of HEIs gave us valuable insights in timetabling in HEIs. HEIs must cope with governmental, economic and institutional influences which eventually results in space-optimisation pressures. In order to keep up with these demands, the increasingly complex timetabling problems have to be solved by state-of-the-art optimisation solutions.

As we are concluding on the main research question, we identify a certain disparity between the theory and practice. Research within the field of HE timetabling is following a somewhat clear-cut pattern, and in particular research in algorithms. Literature in this field seems to lack attention on real implementation of optimisation solutions in timetabling applications. Thus, this implicates that timetabling applications comprise only a limited amount of state-of-the-art research in timetabling solutions. This is unfortunate and results in unused opportunities for both researchers and institutions of HE. However, is this accountable to the prevailing fine-tuning on specific requirements instances, or the fact that it is not regarded as a top trend in information technology according to Gartner (2015) [43]? Perhaps it is about time to align academia and industry.

7. FUTURE RESEARCH
The research model, as shown in figure 2, can be enhanced with additional literature and situational methods in order to do a more profound claim on gap analysis for example. Studies conducted by McCollum (2006) [57] and Pillay (2014) [68] identified such gaps and it would be very valuable to investigate in further detail whether some have been tightened.

8. REFERENCES
[1] 10th International Conference of the Practice and Theory of Automated Timetabling PATAT 2014, 26-29 August 2014, York, United Kingdom


