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PREFACE

The 40th European Conference on Modelling and Simulation (ECMS 2026), held from 23–26 June 2026 at the University of Agder in Grimstad, Norway, marks a significant milestone in the long-standing ECMS conference series. Over four decades, ECMS has established itself as a leading international forum for the dissemination of scientific advances in modelling and simulation, bringing together researchers, engineers, and practitioners from diverse disciplines.

ECMS 2026 continues this tradition by providing a platform for presenting high-quality, peer-reviewed research that advances the theory, methodology, and application of modelling and simulation. The conference addresses a wide spectrum of topics, including computational modelling, simulation frameworks, artificial intelligence in simulation, digital twins, optimisation techniques, and applications across engineering, robotics, supply chains, and complex socio-technical systems.

The conference attracted strong international participation and a high number of submissions, reflecting the increasing relevance of modelling and simulation as enabling technologies in modern science and engineering. All submitted papers underwent a rigorous peer-review process conducted by an international programme committee to ensure the scientific quality of the contributions included in these proceedings.

ECMS 2026 features keynote lectures by Prof. Dmitry Ivanov (Berlin School of Economics and Law), a leading authority in supply chain simulation, digital twins, and agentic AI, and Dr. Monica Malvezzi (University of Siena), an expert in robotics, haptics, and wearable systems, showcasing the role of simulation across both industrial and human-centered domains.

The programme features parallel technical sessions, workshops, and a dedicated student session aimed at supporting early-career researchers. These proceedings represent the collective effort of authors, reviewers, and organisers in advancing knowledge and fostering collaboration within the modelling and simulation community.

We would like to express our sincere gratitude to all authors for their valuable contributions, to the programme committee and reviewers for their dedication and expertise, and to the organising team for their commitment to delivering this special 40th anniversary edition. In particular, we acknowledge the efforts of the General Chairs, Filippo Sanfilippo (University of Agder) and Florenc Demrozi (University of Stavanger), the programme Chairs, Mohammad Poursina (University of Agder) and Fabio Sgarbossa (NTNU Trondheim), and the Organizing Committee member Tomas Blazauskas (Kaunas University of Technology) whose contributions have been essential to the success of ECMS 2026.

We also acknowledge the support of the University of Agder and the University of Stavanger, as well as collaborating institutions, for hosting the conference. We further gratefully acknowledge financial support from the Research Council of Norway.

We hope that these proceedings will serve as a valuable reference for researchers and practitioners and will contribute to future developments and collaborations in modelling and simulation.

A special acknowledgment goes to Martina-Maria Seidel for her precise and dedicated coordination of the conference logistics, and to Elisabeth Rasmussen for the coordination of the local activities.

ECMS 2026 Chairs,

Filippo Sanfilippo, Florenc Demrozi, Mohammad Poursina, Fabio Sgarbossa,
Tomas Blazauskas

40 years of ECMS

It is with great pleasure that I present the proceedings of the 40th ECMS International Conference on Modelling and Simulation (ECMS 2026), a landmark edition that celebrates four decades of continuous scientific exchange, innovation, and collaboration within the modelling and simulation community in Europe and internationally. Held in Grimstad, Norway, this anniversary conference not only marks an important historical milestone for the European Council for Modelling and Simulation (ECMS) but also reaffirms its enduring role as a leading international forum for advancing the theory and application of modelling and simulation across disciplines. Over the past 40 years, ECMS has grown into a vibrant, multidisciplinary platform that brings together researchers, practitioners, and industry experts from around the world. This 40th edition highlights the remarkable evolution of the field, driven by increasing computational power, data availability, and global connectivity, which continue to expand the horizons of modelling and simulation and redefine their impact on science, engineering, and society.

The richness of the contributions included in this volume reflects both the diversity and the depth of the conference programme. ECMS 2026 features a wide spectrum of tracks and thematic sessions that collectively capture the state of the art. These include, among others, business process modelling and industrial operations, digital twins for smart industrial systems, resilient and sustainable supply chains, cybersecurity modelling, and performance evaluation of data-intensive systems. Emerging and rapidly advancing areas such as artificial intelligence and machine learning for simulation, human–robot interaction and collaboration, simulation and optimization, as well as immersive technologies including 3D modelling and virtual/augmented reality, are also prominently represented.

This breadth demonstrates the inherently interdisciplinary nature of modelling and simulation, spanning domains such as computer systems, industry, economics, social sciences, and engineering. It also highlights the increasing relevance of simulation-driven approaches in addressing complex, real-world challenges—from smart manufacturing and digital transformation to sustainability, resilience, and security in modern systems.

An important aspect of ECMS is the visibility and recognition of its scholarly output. The proceedings are widely indexed in major international databases, including SCOPUS, Web of Science (Clarivate Analytics), dblp, and Inspec, ensuring broad dissemination and accessibility of the presented research to the global scientific community. This extensive indexing underscores the quality and impact of the work published in ECMS conferences and further enhances the value of these contributions for authors and readers alike.

As we celebrate the 40th anniversary of ECMS, this volume stands as a testament to the strength, vitality, and continued growth of our community. It reflects not only the achievements of the past but also the exciting opportunities that lie ahead as modelling and simulation continue to evolve and address increasingly complex challenges.
On behalf of the European Council for Modelling and Simulation, I would like to express my sincere appreciation to all authors, reviewers, track chairs, and the conference committees for their invaluable contributions. Their dedication and excellence have made ECMS 2026 a truly remarkable and memorable milestone.
Finally, a special thanks to the ECMS Office Manager and the proceedings Executive Editor, Martina-Maria Seidel for her tremendous work in the organisation of the conferences and editing ECMS proceedings over the last 25 years.

Khalid Al-Begain
President, European Council for Modelling and Simulation (ECMS)

ABOUT THE FOUNDERS OF ECMS

Eugene J. H. Kerckhoffs

Eugene Jules Hubert Kerckhoffs is a Dutch scientist, educator, and pioneer in the field of modelling and simulation, whose career spans more than four decades of research, leadership, teaching, and community building in Europe and beyond. He was born in Heerlen, the Netherlands, on 7 September 1942. After completing his studies at Gymnasium, he entered Delft University of Technology, where he obtained his MSc in Physical Engineering, receiving an “Award for Excellent Research”. Remaining at Delft University throughout his career, Kerckhoffs advanced from Scientific Assistant in the early 1970s to Associate Professor in the 1980s. Meanwhile, he continued his studies and research at the University of Ghent (Belgium), earning a PhD in Computer Science summa cum laude in 1986. In addition to his professorship in Delft, he became a part-time professor at the University of Ghent, where he was a chairholder of a special chair in Simulation Sciences. He also held visiting professorial positions at the Technical University of Vienna (1978), California State University at Chico (1987), and Beijing University of Aeronautics and Astronautics (1991–1992), and delivered during this period guest lectures at the Tsinghua University of Beijing.

Teaching and Research

Professor Kerckhoffs’s professional career was rooted in both teaching and research. His teaching portfolio encompassed Modelling and Simulation, Parallel and Supercomputing, Artificial Intelligence, and Neural Computing — courses he delivered

at Delft, Ghent, and institutions across Western and Eastern Europe, the USA, Canada, and Malaysia. His research interests consistently centered on Modelling and Simulation, with particular emphasis on continuous systems modelling, knowledge-based systems and neural networks in simulation, intelligent simulation environments, and parallel processing implementations of simulated systems. As to the latter, he was instrumental in establishing Delft's first massively parallel NCUBE supercomputer — one of the early milestones in European high-performance computing. His scholarly output includes numerous (over 200) scientific papers, conference presentations, and edited volumes, spanning both theoretical and applied aspects of simulation technologies.

Simulation Societies

Professor Kerckhoffs is recognized as a founding architect of European modelling and simulation societies and communities. In 1979 he was a co-founder of the Dutch Benelux Simulation Society (DBSS) — established informally in 1979 and formally in 1986 — and served for more than a decade as its first Secretary. Through his proactive collaboration as DBSS Secretary with regional simulation societies between 1979 and 1989, he played a key role in the preparatory groundwork for EUROSIM, the Federation of European Simulation Societies, established in 1989 after a long and challenging procedure. His extended report "On the Way to a Federation of (Regional) European Simulation Societies / The Prehistory of EUROSIM (1979–1989)" is published on the history page of EUROSIM's website.

In 1990 he initiated the SCS European Simulation Council (ESC) — which later in 2004 under the presidency of Andrzej Bargiela, evolved into the current independent European Council for Modelling and Simulation (ECMS) — and served as its first President until 1997. On the occasion of 30 years ECMS, he authored Chapter 1, "ECMS: Its Position in the European Simulation History", in the (devoted to the special occasion) book "Seminal Contributions to Modelling and Simulation" (Eds. Khalid Al-Begain and Andrzej Bargiela, Springer, 2016). He continues to serve ECMS as its Historian, documenting its evolution and impact.

His strategic leadership also extended to global roles within the (originally American) Society for Modeling & Simulation International (SCS) — founded already in 1952 — where he was a long-serving member of the Board of Directors and held for two years the executive role of SCS Vice-President for Europe. Prof. Kerckhoffs service has been recognized through his Fellowship in SCS (FSCS, Fellow of the Society for Modeling & Simulation International), awarded "in recognition of his pioneering work in the integration of simulation and AI and neural networks on a parallel hardware platform". He has also received Distinguished Service and Outstanding Contribution Awards from SCS and ECMS. In 2017, he was appointed Officer in the Order of Orange-Nassau by

the Dutch monarchy — a testament to his lifelong contributions to science, the society at large and the simulation community in particular.

Simulation Conferences

Kerckhoffs has played pivotal roles in shaping key international conferences. He served as Secretary of the Scientific Committee for the 7th and 8th IMACS World Congresses (Delft 1983; Sorrento, Italy 1986). He chaired or co-chaired European Simulation Symposia and ECMS conferences, as well as ECMS conference tracks, across Europe and Asia. He acted as Honorary Chair and Best Paper Award Committee Chair for numerous ECMS events. His editorial contributions during this period included leadership roles with the journal Simulation News Europe, and several book series and conference proceedings.

Kerckhoffs pioneering efforts in integrating simulation and AI are evidenced by his co-organization (with G.C. Vansteenkiste) of the working conference “AI Applied to Simulation” at the University of Ghent, 25–28 February 1985, generally regarded as the first European academic event to explicitly combine AI and simulation. It influenced subsequent research in intelligent simulation environments. The conference proceedings (Eds. E.J.H. Kerckhoffs, G.C. Vansteenkiste, B.P. Zeigler) were published in February 1986 under the title “AI Applied to Simulation”, as part of the SCS Simulation Series (Vol. 18, No. 1). Notably, Kerckhoffs later advanced this line of research by implementing combined Simulation/AI methods on a massively parallel supercomputer (an NCUBE with 64 processors).

Retirement

Retired for some twenty years now, Professor Kerckhoffs has been unable to attend his beloved ECMS Conferences since 2018 due to health problems. It is truly a pity that he cannot be present at the 40th ECMS Jubilee Conference, taking place this year, 2026, from 23–26 June in Grimstad, Norway. These days, Kerckhoffs devotes much of his time to philosophical ideas. He is particularly interested in the philosophical movement known as the “simulation hypothesis”, which posits that our entire universe and everything within it — including our thoughts, emotions, and surroundings — could be an artificial construct created by a more highly evolved civilization.

Andrzej Bargiela

Professor Andrzej Bargiela holds a BSc/MSc in Electronics and Informatics from the Silesian Technical University, Poland (1978) and a PhD from the University of Durham, United Kingdom (1984). His academic career spans four decades of contributions to computer science, having held positions as Senior Research Fellow, Senior Lecturer (1884), Reader (1992), and ultimately Professor (1996) at leading British universities.

In 2007, the appointment as Professor of Computer Science at the University of Nottingham, one of the top 100 universities in the world, marked a significant milestone, accompanied by a role as Director of the School of Computer Science at the Malaysia Campus. Between 2011 and 2013, the directorship of Internationalisation in the School of Computer Science at the University of Nottingham further broadened the scope of academic leadership.

His appointment as Director at Large for the European Society for Computer Simulation (SCS Europe), a branch of the SCS Society in the USA, in 2002, marked a beginning of his active contribution to the community of Simulationists in Europe. Recognising the importance of the local financial oversight over conference budgets he led a group of academic colleagues to establish an independent body, the European Council for Modelling and Simulation (ECMS) in 2004 and served as President of this organisation for two terms 2004-2006 and 2006-2008. He was subsequently elected for an additional term 2010-2012.

Representing the ECMS, Professor Bargiela served on the International Panel of 12 Experts formed by the German Funding Council (DFG) to consider strategic investment in Centres of Excellence in Modelling and Simulation for two rounds of funding in 2005 and 2006. In 2007 he served on the German Funding Council DFG Panel considering investment in German Centres of Excellence in High-performance Computing.

As the founding Director and Chief Executive Officer of INFOHUB Ltd., a research spin-off company established in 2003, Professor Bargiela bridges the gap between academic research and commercial applications in human-centered computing, data mining, and decision support.

The Full Professorship conferred by the President of Poland in 2005 recognised the distinguished standing of this body of work. Professor Bargiela was invited to share his expertise through Visiting Professorship appointments at universities in New Zealand (University of Canterbury), Poland (Krakow University of Technology), Japan (Tokyo Institute of Technology), Finland (Aalto University), Italy (University of Bari), and Canada (University of Alberta) which reflects the international reach and collaborative nature of his research.

ECMS in a broad historical perspective

Eugene J.H. Kerckhoffs
ECMS Historian

In this essay the author is not presenting an official or authoritative history. Rather, his account is based on own memories, impressions, and experiences. Although the author has tried to describe the events as accurately as possible, inaccuracies or gaps may be possible, since others might remember or interpret events differently.

ECMS, the European Council for Modelling and Simulation, is an independent forum of European academics and practitioners dedicated to the research, development, and application of modelling and simulation. ECMS organizes an annual conference, also named ECMS, now however standing for the European Conference on Modelling and Simulation (the context should make clear whether the Council or the Conference is meant). The next edition in the ECMS conference series will take place from 23–26 June 2026 in Grimstad, Norway. This will be the 40th conference in the ECMS series, making it a Jubilee Conference. On the occasion of this auspicious event, the author presents in this essay the history of ECMS in a broad historical perspective, ranging from the early 1970s to the present day. This means that events of significance and influence — along with a number of name changes — from long before the establishment of ECMS are also included.

1. Prehistory: the seventies and eighties

1.1 Simulation Societies

We begin our considerations in the early seventies, long before the first Conference in the ECMS (formerly named ESM) series, held in 1987 in Vienna. In the early seventies, the emphasis was mainly on continuous rather than discrete (event) simulation. Analogue computers — and later hybrid computers — were used extensively; most of the early “simulationists” came from the analogue computing community.

The leading international Simulation Societies at that time were **AICA** (Association Internationale pour le Calcul Analogique), founded in Brussels in 1955, and SCS (Society for Computer Simulation), founded by John McLeod in San Diego, California, in 1952. In 1976, AICA was renamed **IMACS** (International Society for Mathematics and Computers in Simulation) to reflect the general evolution from analogue computer techniques, through hybrid computer simulation, to the use of digital simulation languages. Although SCS was primarily a national (American) society, it is considered here to be international because it had, at that time, one

non-American Council: **UKSC** (United Kingdom Simulation Council), established in 1969. The Society for Computer Simulation later changed its name to the current "Society for Modeling and Simulation International", while retaining the abbreviation SCS.

In the Scandinavian countries, we had the "Skandinaviska Analogimaskinsällskapet" (Scandinavian Analogue Computer Society), founded in 1959 and renamed **SIMS** (the Scandinavian Simulation Society) in 1968.

In addition to the international Simulation Societies, there were of course also national and local ones. The UKSC has already been mentioned above. In the Netherlands, there was SAHR (the Section for Analogue and Hybrid Computation of the Dutch Society for Informatics), later renamed SvS (Section for Simulation). There were many more across Europe, including an active and influential simulation group in what was then Czechoslovakia.

1.2 Simulation Conferences

As for Simulation Conferences organized in Europe during the 1970s, the most relevant series was the triennial AICA World Congress (renamed IMACS World Congress in 1979). These congresses were held in various European cities — the 6th AICA World Congress in Munich in 1970, the 7th AICA World Congress in Prague in 1973, the 8th AICA World Congress in Delft in 1976, the 9th IMACS World Congress in Sorrento in 1979, and so on (see Fig.1). In 1975, the UKSC started its own international conference series in Bowness-on-Windermere in the Lake District. In addition to these events, numerous simulation conferences (such as the annual SIMS conference) and local simulation meetings were organized.

It was during the 8th AICA World Congress in Delft in 1976 that AICA officially changed its name to IMACS, maintaining the numbering of its congresses. From a historical perspective, the 9th IMACS World Congress in Sorrento in 1979 was particularly significant. Within the IMACS Board of Directors, disagreements arose concerning the location of the next World Congress. A majority of the Board favored selecting a non-European venue (Montreal), while several European Board members strongly opposed this and insisted on maintaining a European location. Ultimately, Montreal was chosen. This decision, however, prompted several prominent European simulationists to join forces and begin organizing international European events independently of IMACS — that is, no longer under its umbrella or responsibility. The first ideas for establishing European common-language-based Simulation Societies emerged during the 9th IMACS World Congress. This marks the earliest origin of what would eventually lead to the founding in 1989 of the Federation of European Simulation Societies, named EUROSIM (see Section 1.3).

Another consequence was that some leading simulationists, who until then had been very loyal to IMACS, began to shift their attention toward the other major organization in simulation world: SCS. They became increasingly willing to work for the benefit of SCS in continental Europe (outside the UK, the domain of the SCS Council UKSC) and even to compete with IMACS. This development marks the beginning of what would later result in the establishment of the SCS European Office in 1985 (see Fig.1).

1.3 The establishment of new European (common-language-based) Simulation Societies

Having already UKSC (with English as common language) and SIMS (with the Scandinavian languages imagined as "common" language), the first new common-language-based Simulation Society was **DBSS** (Dutch Benelux Simulation Society). It covered the Netherlands and the Flemish part of Belgium, with Dutch as common language. DBSS was informally established in 1979, half a year before the 9th IMACS World Congress. Its legal founding followed much later, in 1986; but especially during its informal period it was considerably influential within the European simulation community (for instance, the idea to establish common-language-based European Simulation Societies and looking for support within the European simulation community came from DBSS in its informal period).

At a crucial meeting on June 15th, 1981, in Brussels — initiated by DBSS and attended by representatives of DBSS, UKSC, SIMS, and several German simulationists — it was agreed that: 1)Walter Ameling (Aachen, Germany) would take the initiative to found a German-speaking Simulation Society; 2) the common-language–based Simulation Societies would jointly initiate a new triennial congress series named **ESC** (European Simulation Congress); 3) the 1st ESC would be held in Aachen (Germany); and 4) a Federation of European Simulation Societies would be established in the future.

As a result of this meeting, the German-speaking Simulation Society was founded in April 1982 (as a Special Interest Group of GI, the German Society for Informatics) during a simulation symposium in Erlangen. The society was named **ASIM** (Arbeitsgemeinschaft für Simulation) and covered Germany, Austria, and the German-speaking part of Switzerland.

The 1st European Simulation Congress (ESC83) was organized by ASIM and held in Aachen in 1983. The 2nd congress in the ESC series was organized by DBSS and held in Antwerp in 1986, and the 3rd was organized by UKSC and took place in Edinburgh in 1989. During this third congress, the Federation of European Simulation Societies — named **EUROSIM** — was established and officially announced! (The

original so-called EUROSIM umbrella, symbolizing EUROSIM's role as an umbrella organization for European Simulation Societies and bearing the signatures of the founders, may be still in the possession of the EUROSIM-Board.)

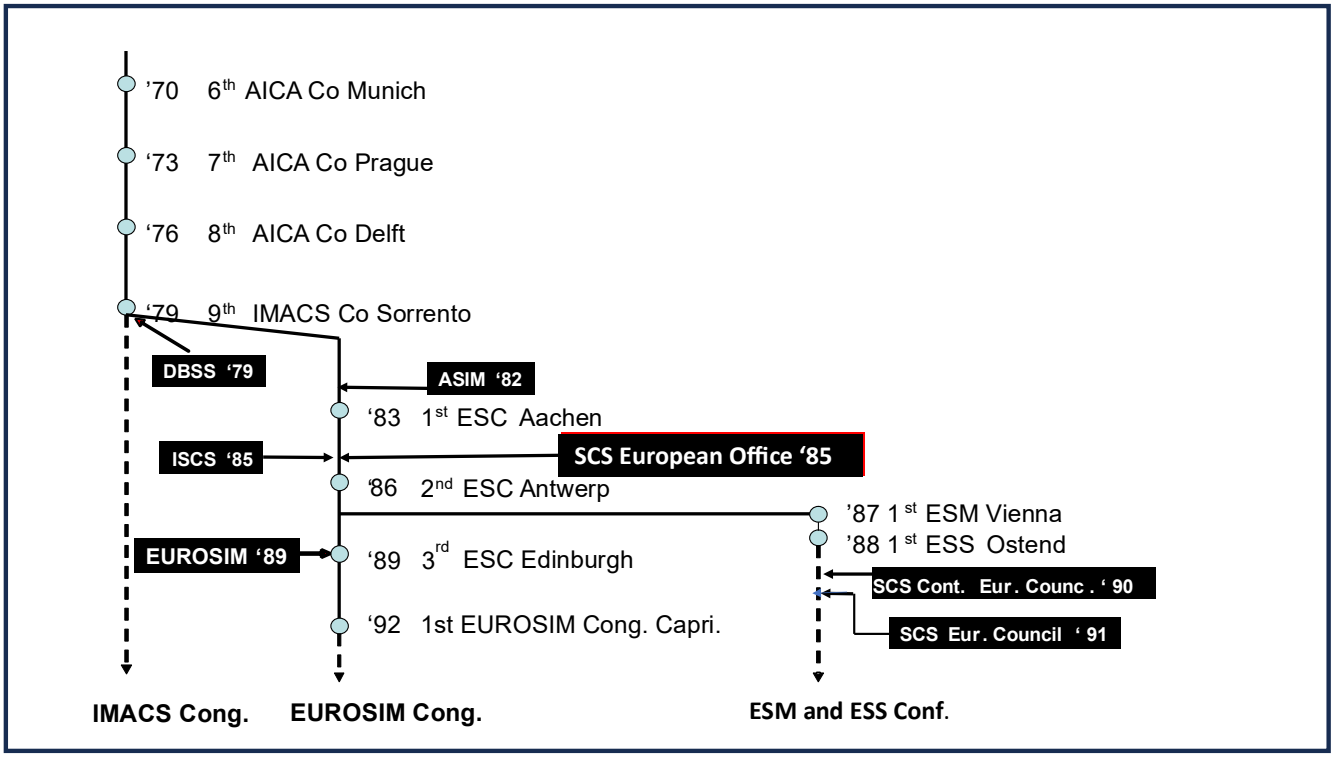

Fig. 1. Schematic representation of the "births" of simulation societies, simulation conferences, and other events. The two vertical branches on the left represent, respectively, the continuation of the triennial IMACS World Congresses and the continuation of the triennial EUROSIM Congresses (following the original triennial ESC series). In the third branch on the right, ECMS enters the scene with its annual ESM and ESS conference series, and later ultimately the annual ECMS series (see Sect. 2.1 and Fig. 2).

Fig.1 implies in the second vertical branch that the triennial ESC series was succeeded by the triennial EUROSIM Congress series: the 1st EUROSIM Congress in Capri in 1992, the 2nd in Vienna in 1995, the 3rd in Helsinki in 1998, and so on up to the present day. Meanwhile, EUROSIM has come to include many more Simulation Societies than the original ones, such as FrancoSim (French-speaking Simulation Society), ISCS (Italian Society for Computer Simulation, established in 1985), UKSim (successor of UKSC since 1991), HSS (Hungarian Simulation Society), and others. At present, EUROSIM encompasses about 15 European Simulation Societies (member societies are distinguished in full members, members, observer members, and members in reorganization). On the left side of Fig.1, the years of establishment of the Simulation Societies DBSS (still informal), ASIM, ISCS, and their umbrella federation EUROSIM are indicated.

The third vertical branch on the right side of Fig.1 implicitly introduces the main topic of this essay: the ECMS series of conferences. During the period 1987–2005,

however, the underlying organizational bodies had different names and organized conferences under names that differed from the current annual ECMS conference. More explaining information is dealt with in the next Sects. 1.4, 2.1, 2.2 and 2.3.

1.4 Further penetration of SCS in Europe, the SCS European Office

As mentioned earlier, in the 1970s SCS had one European Council: the UKSC. Its membership outside the United Kingdom was very limited. On the European continent, most simulationists primarily attended and organized IMACS or IMACS-related meetings; only a few showed really interest in SCS activities. Toward the end of the decade, however, several influential simulationists in continental Europe began to pay increasing attention to SCS and its activities. They worked within Europe to promote SCS, encouraging colleagues to attend SCS congresses in the United States or Canada.

They also facilitated affiliation agreements between European Simulation Societies and SCS — for example, the first European society to establish such an agreement was DBSS (June 1981). Some European individuals later joined the SCS Board of Directors and even its Executive Board (President, Past-President, Secretary, Treasurer, and several regional Vice-Presidents). In 1983, Ghislain Vansteenkiste (University of Ghent, Belgium) became Vice-President (VP) for Europe, succeeding the first VP for Europe, Roy Crosbie. Vansteenkiste held this position for nine years. The next and last Vice-President for Europe was Eugene Kerckhoffs (Delft University of Technology, the Netherlands), who served for only two years (1992–1994), as SCS decided to replace regional Vice-Presidents with special-interest Vice-Presidents (such as Vice-President for Publications, Vice-President for Conferences, etc.).

During the 1980s, cooperation between SCS and European Simulation Societies also increased, particularly through sponsorships and the organization of conference sessions. For instance, DBSS organized two sessions at the 1984 SCS Summer Computer Simulation Conference in Boston. It was during this conference that, in special brainstorming sessions, the first ideas emerged to establish an SCS European Office somewhere in Europe.

In June 1985, the SCS Board of Directors decided to establish an **SCS European Office** in Ghent, Belgium (see also Fig.1). The choice of Ghent was obvious, as Ghislain Vansteenkiste, professor at the University of Ghent, was the SCS Vice-President for Europe. The author's impression at that time was that there were no real financial problems with respect to the establishment of the European Office; SCS as a member of the NCC (National Computer Conference) in the United States received an annual contribution from the profits generated by this large conference, which attracted a lot of participants. The author had also the impression that, with the

establishment of a European Office, SCS expected a significant increase in its European membership. However, this expectation was barely fulfilled, as some influential European simulationists did not want at that time to become members of SCS.

2. The birth and continuation of the conference series ESM and ESS

2.1 The activities of the SCS European Office

After the decision to establish an SCS European Office in Ghent, Belgium, the first priority was of course to appoint a managing director of the Office. A committee consisting of Charlie Pratt (in that time managing director of SCS, San Diego, CA), Ghislain Vansteenkiste (Ghent, Belgium), Mrs. Lieve Vansteenkiste, and Eugene Kerckhoffs (Delft, the Netherlands) selected Philippe Geril from twelve candidates as the managing director of the newly established SCS European Office. He began his work on September 1, 1985; as of October 1, 1985, he was employed by the University of Ghent with a salary guarantee from SCS.

Geril's formal superior was SCS managing director Charlie Pratt, but in practice he was supervised on a daily basis by Ghislain Vansteenkiste, with some support of Eugene Kerckhoffs. These four individuals together constituted, so to speak, the SCS European Office, although Philippe Geril carried out the executive work. Charlie Pratt was later succeeded as SCS managing director — and thus as the overseer of the SCS European Office — by Chip Stockton, who in turn was succeeded by Steve Branch.

Initially, the sole task of the European Office managing director Philippe Geril was to improve the existing journal "Simulation News Europe" (SNE), founded in 1979 by Ghislain Vansteenkiste. He enhanced the journal's appearance, collected news from the European simulation community, and managed its further preparation. (The journal was later taken over in 1989 by Felix Breitenecker (Vienna), who, as editor-in-chief, transformed it into a truly professional and high-quality publication; SNE stands nowadays for "Simulation Notes Europe.)

Meanwhile, the aforementioned NCC (National Computer Conference) ceased operations in 1985/86, ending SCS's annual income as NCC member. SCS was obliged to organize additional activities to maintain its financial stability. In addition to coordinating the "Simulation News Europe", European Office managing director Philippe Geril was tasked with coordinating and managing a new series of European conferences, the **ESM** (European Simulation Multiconference), modeled after the existing SCS Summer Computer Simulation Conferences in the USA.

The first ESM conference took place in Vienna, 7–10 July 1987, chaired by H. Adelsberger and coordinated — financial responsibility included — by the SCS

European Office. (Participants of this first ESM will undoubtedly remember the well-known “Heurigenabend” in a small village near Vienna.) The second ESM was held in Nice (France) in 1988, again coordinated by the SCS European Office; see also Fig. 2.

To the author it felt as though it became more and more clear that a series of a single annual conference was insufficient to cover the expenses for the SCS European Office. It was decided to launch a series of a second annual conference alongside ESM. After discussions with representatives of the European simulation community, SCS initiated a new series called USER, intended as a meeting platform for both producers and users of simulation software. The first USER conference took place in Ostend (Belgium), 6–8 September 1988; the General Chair was Jef Baynham of Applied Dynamics (a manufacturer of hybrid computers) and the Program Chair was Eugene Kerckhoffs. From 1990 onward, the series continued under a new name: **ESS** (European Simulation Symposium) — with retroactive effect, meaning that the USER conference is actually the 1st ESS conference; see Fig.2.

It should be noted that the SCS European Office already had practical experience in managing scientific conferences before launching the ESM series in 1987. It was heavily involved in the organization of the 2nd ESC (European Simulation Congress) in 1986 in Antwerp. Up to 1986, there was a good understanding between the “EUROSIM-oriented” and “SCS-oriented” simulationists in Europe. After 1986, this changed. The author’s experience at that time was that gradually an increasing competitive relationship developed between the two groups. This explains the third vertical branch in the schematic representation of Fig.1, which shows the first ESM and ESS conference in 1987 and 1988, respectively.

2.2 The ESM and ESS series of conferences

In the previous Sect. 2.1 we discussed the establishment of the ESM series of conferences. The 4th ESM 1990 in Nuremburg (Germany) was an important and really successful conference. During this conference a proposal has been formulated and discussed to establish, in addition to the UKSC (United Kingdom Simulation Council), an SCS Continental Europe Simulation Council (**CESC**) in order to have a scientific organizational body behind the ESM and ESS series of conferences; later in the same year 1990, this proposal has been approved by SCS, see next Sect. 2.3. Looking to the number of participants, the largest ESM was the 5th ESM 1991 in Copenhagen (Denmark) with 239 attendants.

In addition to ECM, in the previous Sect. 2.1 the establishment of the ESS series of conferences was also discussed. The 1st ESS was held in Ostend, Belgium (1988), the 2nd and 3rd ESS were both held in Ghent (1990 and 1991). (In 1989 there was no ESS because of the 3rd ESC (European Simulation Congress) in Edinburgh, during

which EUROSIM has been established!) The real breakthrough in the ESS series came with the 4th ESS 1992 in Dresden and the 5th ESS 1993 in Delft. Special reference should be given to the 14th ESS 2002 in Dresden (Germany), since here for the first time Mrs. Martina-Maria Seidel came on the scene to assist conference director Rainer Rimane in the coordination of the conference; later she would play a key role in the coordination of ECMS conferences and as managing editor of their Proceedings, up to nowadays. In Fig.2 the third vertical branch of Fig.1 is extended, showing all ESM and ESS conferences (up to and included 2004). Gradually, the ESS came to be adopted more and more of the same structure and scientific content as ESM. Both conferences were considered the flagships of SCS Europe.

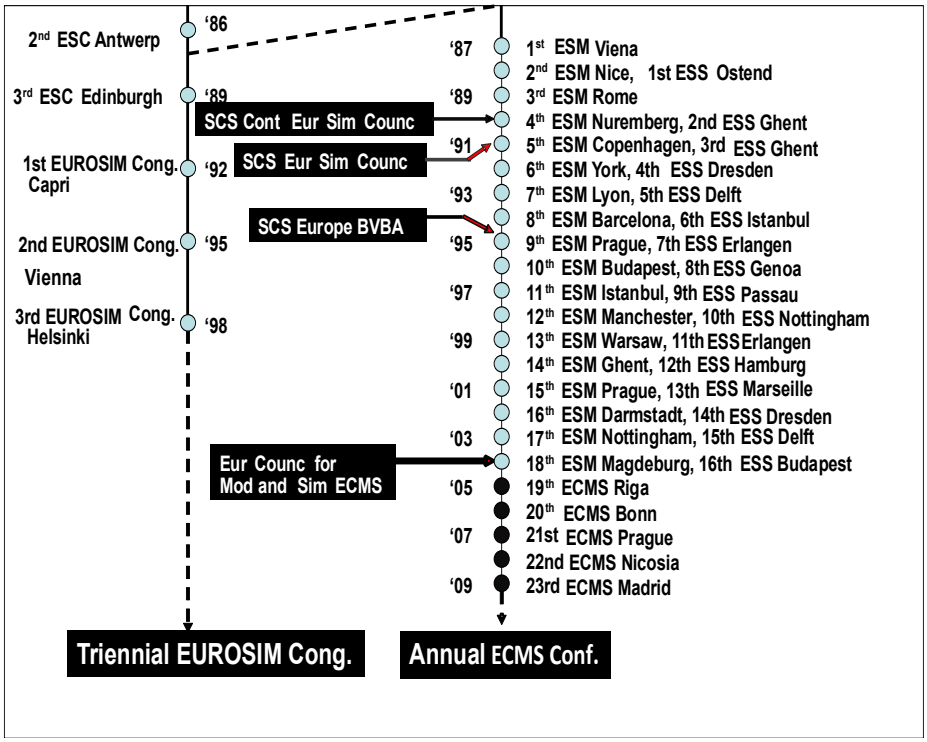

Fig.2: The ESM and ESS series of conferences. During the 18th ESM 2004 in Magdeburg. it was decided to continue the Council, but now named ECMS, and have only one annual Conference ECMS (formerly ESM) and no ESS anymore.

2.3 SCS European Simulation Council, SCS Europe BVBA

In order to provide a forum to the SCS members outside the UK and a scientific body behind its European conference series ESM and ESS, SCS decided by decision of the Board of Directors in July 1990 to approve the proposal — as mentioned in the previous Sect 2.2 — to establish a **Continental Europe Simulation Council (CESC)** of SCS. The chairman of this new SCS Council was its initiator, Eugene Kerckhoffs.

All SCS members outside the UK were automatically members of CESC. One year later in 1991, CESC was reorganized to cover whole Europe including the UK and was therefore renamed **European Simulation Council (ESC)**; all European members of SCS were also members of ESC. (Later the SCS Mediterranean Council has been established initiated by Agostino Bruzzone which had Southern Europe as area of interest, but this is beyond the scope of this essay.)

The UKSC was dissolved as SCS Council and became an independent Simulation Society under the name **UKSim** and a member society of EUROSIM, the Federation of European Simulation Societies. Ignoring the one-year CESC, from 1990 onward the SCS European Simulation Council (ESC) served as the coordinating scientific body behind all ESM and ESS conferences, up to and including the 18th ESM in Magdeburg (2004) and the 16th ESS in Budapest (2004); see Fig.2. The Board of ESC decided on conference locations, dates, scientific themes, tracks, and invited speakers. The chairs (presidents) of the ESC Board during the period 1990–2004 were, in chronological order: Eugene Kerckhoffs (The Netherlands, 1990–1997), Alexander Verbraeck (The Netherlands, 1997–2002), Andrzej Bargiela (UK, 2002–2006; during his presidency ESC transitioned into the independent council ECMS in 2004).

In 1995, the SCS European Office was transformed into **SCS Europe BVBA (BVBA)** is the Belgian equivalent of “Limited”), because of financial reasons. The shares of the BVBA were distributed among SCS and three private individuals: Philippe Geril, Rainer Rimane, and Eugene Kerckhoffs, with Philippe Geril as the statutory director. Besides organizing conferences, the BVBA published books and book series. From the perspective of financial stability, the BVBA’s affairs were not progressing well. Philippe Geril and Eugene Kerckhoffs resigned from their positions and Rainer Rimane became the BVBA’s executive director. Some years later the author was informed by the executive director that the BVBA was legally dissolved. The final activity of the BVBA was the coordination and partial financial management of ESS 2004 in Budapest.

In Fig.2 the establishment of the SCS European Simulation Council (ESC) and SCS Europe BVBA, as well as the later emergence of **ECMS**, are clearly indicated.

2.4 ECMS and its Conferences

From 1995 up to and included 2004, all ESM and ESS conferences were under the joint responsibility and control of the SCS European Simulation Council (ESC) and SCS Europe BVBA. The ESC handled the selection of conference locations, dates, topics, and tracks, as well as the appointment of key conference people (such as the general chair, program chair, track chairs, and invited speakers). The BVBA was

responsible for practical coordination, financial management, and the management of the Conference Proceedings.

Over time, however, this arrangement became increasingly unsatisfactory for Board members and other active members of the ESC. The fact that, prior to July 2004, SCS Europe BVBA had full financial control — control that was felt opaque and non-transparent to others — caused frustration, since the ESC had never been involved in the financial(!) management of the European conferences. It was Andrzej Bargiela, at that time president of the ESC, who took the initiative to change this situation fundamentally.

At the ESC Board meeting in Budapest (October 2004), held during the 16th ESS, it was decided to replace the SCS Simulation Council ESC with the ECMS (European Council for Modelling and Simulation). The ECMS was proposed as an autonomous member society of SCS, with its own budget and accounts independent of SCS. As a result, the services of SCS Europe BVBA were no longer required, since the ECMS was established as a body taking full financial responsibility for the simulation conferences and enabling more direct involvement of the volunteers, organizing these conferences, in the decision-making processes.

It was further decided to organize only one conference per year instead of the two held previously. The ESM series would be continued, including its numbering, but now under the name ECMS series, and the ESS series would be discontinued. The name change was necessary because the BVBA was the legal owner of the original name ESM. Consequently, the next conference in the ECMS (formerly ESM) series would be the 19th ECMS, held in Riga (Latvia) in June 2005.

We have to emphasize that the driving and inspiring force behind all these developments was Andrzej Bargiela; he was the initiator of the ECMS as it still exists today.

During the ECMS Board meeting at this Riga conference, ECMS and the principles behind it were discussed again in the presence of François Cellier, who was expected to inform the SCS Board. (Interestingly, in August 2005 — barely two months later — the SCS Board of Directors decided that all its regional Councils would be converted into autonomous regional Councils with their own accounts.) Khalid Al-Begain succeeded Andrzej Bargiela as ECMS President in July 2006; at the ECMS Board meeting in July 2008 in Nicosia, Cyprus, his two-year term was extended for another two years.

Of course, organizing the annual ECMS conference would not be possible without the support of a Conference Office to manage the paper review process, oversee the editing of the Proceedings, and, last but not least, host the conference and ensure proper registration of attendees. ECMS was fortunate to find in

Martina-Maria Seidel someone who would run this office in an exceptionally competent manner. She is the Office-manager up to present.

2.5 ECMS: some additional remarks

ECMS has a website (https://scs-europe.net/cms) providing information about the ECMS Board, the ECMS Editorial Board, ECMS Communications, ECMS activities, and more. As extensively discussed in the previous Sect. 2.4, from 2005 on, the ESM conferences were transitioned into ECMS conferences. Below, all ECMS conferences held from 2005 onward are listed:

19th ECMS 2005: Riga, Latvia	**20th ECMS 2006: Bonn, Germany**
21st ECMS 2007: Prague, Czech Republic	**22nd ECMS 2008: Nicosia, Cyprus**
23rd ECMS 2009: Madrid, Spain	**24th ECMS 2010: Kuala Lumpur, Malaysia**
25th ECMS 2011: Krakow, Poland	**26th ECMS 2012: Koblenz, Germany**
27th ECMS 2013: Ålesund, Norway	**28th ECMS 2014: Brescia, Italy**
29th ECMS 2015: Albena (Varna), Bulgaria	**30th ECMS 2016: Regensburg, Germany**
31st ECMS 2017: Budapest, Hungary	**32nd ECMS 2018: Wilhelmshaven, Germ.**
33rd ECMS 2019: Caserta, Italy	**34th ECMS 2020: Virtual Event, UK**
35th ECMS 2021: Virtual Event, UK	**36th ECMS 2022: Ålesund, Norway**
37th ECMS 2023: Florence, Italy	**38th ECMS 2024: Krakow, Poland**
39th ECMS 2025: Catania, Italy	**40th ECMS 2026: Grimstad, Norway**

The 34th and 35th ECMS conferences (in 2020 and 2021 respectively) were on-line conferences. More detailed information can be found in the website's ECMS DLIB Page (https://www.scs-europe.net/dlib/dl-index.htm).

As noted in the next Sect.3 (Final Note), all things considered that have taken place in the past, it is natural and transparent to name all EMS conferences shown in Fig.2 ECMS conferences, and to designate the underlying organizing bodies likewise under the name ECMS. Having said that, we list all ECMS Presidents in chronological order: Eugene Kerckhoffs (the Netherlands, 1990-1997), Alexander Verbraeck (the Netherlands, 1997-2002), Andrzej Bargiela (UK, 2002-2006; during his presidency in 2004 ESC changed into ECMS), Khalid Al-Begain (UK, 2006-2010), Andrzej Bargiela (2010-2012), Evtim Peytchev (UK, 2012-2014), Khalid Al-Begain (UK, 2014-2018), Lars Nolle (Germany, 2018-2021), Mauro Iacono (Italy, 2021-2025), Khalid Al-Begain (UK, 2025-current).

3. Final note

From this essay it becomes clear that the history of ECMS is complicated. However, one has to realize that all mentioned events — even those in the seventies and eighties — have, in their mutual cohesion, contributed to the eventual establishment of the ECMS as we know it today, both as independent Council and as conference series. Without these earlier developments, ECMS might never have existed at all.

The present ECMS as a Council emerged from the former “SCS European Simulation Council” (ESC), founded in 1990 on the initiative of Eugene Kerckhoffs — we hereby waive the one-year “SCS Continental Europe Simulation Council”. ESC was therefore the predecessor organization of ECMS, which still carries, so to speak, the “genes” of its predecessor, but which after 2004 also underwent significant changes on the initiative of Andrzej Bargiela. ECMS took full financial control over its activities, particularly its annual conference. Of the two annual conferences organized by ESC — the ESM and ESS conferences — only the ESM was continued, but now under the name ECMS Conference.

With a view to all developments that had taken place in the past, a natural, obvious, and more transparent procedure was to regard all ESM conferences listed in Fig.2 as ECMS conferences, and to adjust the numbering of the ECMS conferences accordingly. All underlying organizing bodies were likewise designated under the name ECMS (as Council). In the author’s interpretation, this reflected the common view of most people and parties involved. The first ECMS conference therefore took place in 1987 in Vienna, which means that the 2026 conference in Grimstad (Norway) is the 40th ECMS conference — a true Jubilee Conference!

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Integrating Behavioural Factors into the Fashion Renting Supply Chain: A Simulation-Based Approach

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KEYWORDS

Fashion renting, Customer behaviour, Sustainable supply chain, Circular economy, Hybrid Simulation

ABSTRACT

The fashion industry has a significant environmental impact. To minimize its effects, circular business models like fashion renting emerged. However, simulation models that combine supply chain operations with customer behaviour to assess environmental sustainability are still underexplored. This study develops a simulation model to evaluate how fashion renting supply chains perform when customer behaviours are integrated. Using a real-world use case, this research compares six scenarios with different rental periods, transport frequencies, and truck types. The results indicate that higher transport frequencies increase the share of renting among enjoyment-driven customers but can negatively impact sustainability. Notably, the findings demonstrate that fashion renting is not inherently more sustainable than traditional buying, presenting underperforming results in some scenarios. Only specific supply chain configurations successfully lowered aggregate emissions. This research highlights the importance of aligning supply chain design with behavioural factors to achieve true sustainability.

INTRODUCTION

The fashion industry plays an important role in the global economy, involving more than 300 million individuals across its supply chain and moving approximately USD 1.3 trillion (Gyde & McNeill, 2021). On the other hand, the fashion industry is one of the most impactful, both in terms of resource utilization and pollution (EUR-Lex, 2022; Mukendi & Henninger, 2020), generating 10% of the world greenhouse gas emissions (Kala & Chaubey, 2024). In this context, the shift toward more sustainable and circular business models is becoming increasingly urgent, and fashion renting, can allow to extend the product life cycle and reduce environmental impact (Mont, 2002).

Considering fashion's significant environmental impact and its capacity for change, comprehending the dynamics of fashion renting within this sector can enhance broader initiatives toward circular economy practices, potentially providing a model for other businesses seeking sustainability (Lang et al., 2025). These dynamics, in fashion renting systems, are strongly influenced by customer behaviour, an aspect that has been studied by several authors in the literature (Ahmed et al., 2024; Lang & Zhang, 2024; Noe & Hyun, 2024).

Simulation models offer a valuable approach to analysing complex systems and have already been applied in other context to evaluate the performance of renting systems (Roci & Rashid, 2023). However, existing studies rarely combine the modelling of customer behaviour with a quantitative assessment of the environmental sustainability of fashion renting systems. This gap limits the ability to fully understand and capture how behavioural dynamics influence sustainability outcomes and to support decision-making. As suggested by Quadras et al., 2025, future research is needed to develop quantitative models that integrate customers' behavioural factors into decision support systems for renting businesses.

In response to this gap, this study aims to develop a simulation model that incorporate customer behaviour to assess the sustainability performance of the renting system and further support companies in designing and managing successful sustainable fashion renting supply chains. Specifically, this study aims to address two main research questions:

- RQ1: How can customer behavioural factors be integrated into simulation-based decision support systems for assessing the environmental sustainability of fashion renting businesses?
- RQ2: How do fashion renting supply chain configurations influence the sustainability performance of the renting system when behavioural factors are considered?

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The study is presented as follows: section 2 provides the literature background. Section 3 describes the simulation model and the scenario configuration. Section 4 presents the results of the simulated scenario and their discussion, finally, section 5 concludes the paper highlighting the main contribution, limitations and further research.

LITERATURE BACKGROUND

Factors influencing customer behavior

There are different factors that influence the customer behaviour in fashion renting business models. The main factors and their average impact were identified within a previous systematic literature review (Quadras et al., 2025). The factor of enjoyment emerges as the most significant positive factor with a correlation of 0.7 on the customers intention to rent fashion (Jain & Mishra, 2020; Kim & Jin, 2020; Lang et al., 2019). Enjoyment is the pleasure derived from using luxury fashion items or from the collaborative consumption process. It can also be understood as the pride derived from the experience of treasure hunting for luxury rentals. Fashion renting (also known as clothing libraries or collaborative consumption), has emerged as a modern business model where customers do not purchase items, but rent them for a certain period, allowing extension of the product life cycle and reduction of environmental impact. This business model, which falls within the Product-Service System (PSS) research area, is a clear strategy that companies can adopt to transition towards a circular economy and therefore a more sustainable consumption of fashion (Mont, 2002). Hence sustainability is assumed to be a driving factor for the fashion renting business case. Sustainability factors are the level of awareness and concern a customer has for environmental issues related to clothing production and waste. It reflects the customer's consideration of environmental impact when making consumption choices, prior engagement in sustainable practices and the perceived environmental benefits of online fashion renting, like reducing waste and resource conservation (Jain & Mishra, 2020; Kim & Jin, 2020; Savelli et al., 2024).

Sustainability factors in Supply Chain Management Simulation

Sustainability in supply chains is characterized by the integration of environmental, social, and economic aspects within the supply chain operations (Adhitya et al., 2011; Barbosa et al., 2023). The effective management of sustainable supply chains requires the adoption of innovative tools aiming at achieving operational excellence and enhancing sustainability performance (Mangla et al., 2020). In this context, simulation modelling has emerged as a valuable tool to evaluate sustainable alternatives to conventional supply chain configurations. Existing literature on the application of simulation within sustainable supply chain management mainly focuses on the energy consumption of supply chains (Allen et al., 2019; Che et al., 2022; Fornasiero et al., 2017; Youssef et al., 2023). Further approaches include the reduction of carbon dioxide equivalent (CO_2) emissions (Jaegler & Burlat, 2012; Jager et al., 2017; Ketenci et al., 2025) or refer to the circularity of products in order to support waste reduction (Moreno et al., 2019). Simulation is commonly used to conduct scenario analyses based on a "what-if" logic, enabling the comparison of alternative supply chain configurations. Often, Agent-Based Modelling (ABM) and Discrete Event Simulation (DES) are employed in combination (Jager et al., 2017; Youssef et al., 2023). To support the simulation of distribution processes, Geographic Information Systems (GIS) have been integrated to account for realistic logistics routes (Barbosa et al., 2023). For example, Jaegler & Burlat 2012 model different supply chain configurations within the cooler manufacturing supply chain using DES to support supply chain management to select eco-friendly supply chains. Che et al. 2022 compare alternative supply chain configurations, explicitly considering centralized versus decentralized decision-making approaches using simulation. Moreover, Moreno et al. 2019 model the redistribution processes of plastic bottles and cardboard packaging fostering circular economy. Furthermore, Fani et al. 2025 use DES to compare supply chain network configurations to assess the trade-off between sustainability and service level in terms of time.

Regarding the fashion renting supply chain, the literature remains limited. Fani et al., 2022 employ a hybrid simulation approach to analyse the impact of customer behaviour in retail stores and its effects on peer interactions and business performance during and after the implementation of a rental service. Fani & Bandinelli, 2023 compare the environmental impact of conventional fashion supply chains and fashion renting supply chains using a hybrid simulation approach. Doing this, they model the actual customer behaviour, but do not analyse the effects on customer behaviour. Furthermore, Kumar et al., 2022 apply DES to model business-to-business workwear garment rental operations, with a specific focus on inventory management, but not addressing the behaviour of the customers. Therefore, this research aims to model different fashion renting supply chain configurations, integrate customer behaviour and analyse the impact on the sustainability performance of the renting system.

MODEL DESCRIPTION AND SCENARIO CONFIGURATION

Following the steps of simulation studies (Banks, 1999), the fashion renting system has been abstracted into a conceptual model showing the logical relationships concerning the components and the system structure, and then translated into a computerized model. The supply chain is modelled using AnyLogic™ simulation software. This section describes the mathematical modelling and the scenario configuration. The parameters used are described in Table 1.

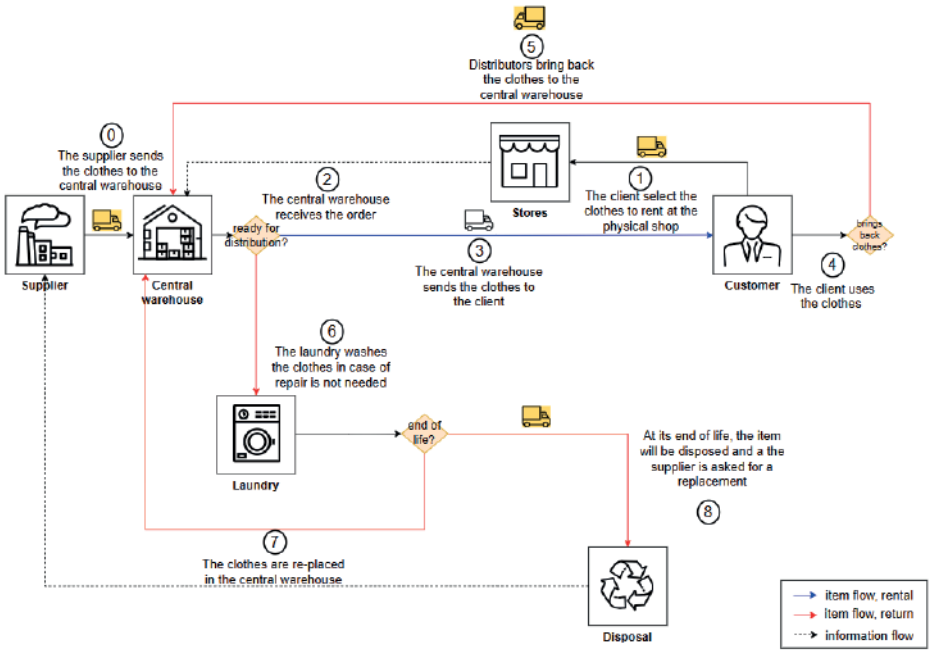

Figure 1: Fashion renting supply chain

Table 1: Parameters for mathematical modelling

Symbol	Description
K	Set of Retail Stores
P	Set of Items (Products)
C	Set of Item Categories
P_{CK}	Set of items (products) of category C in the retail store K
ξ_c^{buy}	Emission of buying new item from category c
$\xi_{p,c,k}^{agg}$	Aggregate emissions of rented item p, from category c at store k
$S(t)$	State Variable that represents the latent satisfaction level at observation time t.
E_i	Impulse Magnitude that represents positive or negative experiences retrieved from the database ($\in \{+1, -1\}$).
t_i	Event Timestamp, i.e., the specific point in time when the i-th experience occurred
e	Euler constant
β	Decay Coefficient, a positive parameter ($0 < \beta < 1$) that determines the rate of information loss over time.
$\lambda(t)$	Current rate of return
λ_0	Return rate of a neutral customer

The supply chain is represented in Figure 1. The actors involved in the value chain are the main representatives of the fashion renting supply chain: supplier, central warehouse, stores, customer, and laundries. The supply chain considers only in-store rental, and the possibility of recycling clothes is not included. The items (parameter P in Table 1), divided into eight different item categories (parameter C in Table 1), and information flows within the system and among the involved stakeholders are displayed in Figure 1. This configuration is based on the use case of Please Don't Buy company placed in Italy (Arrigo, 2023).

The supply chain system is composed by one central warehouse, located in Carpi, and six stores (parameter K in Table 1) located in Rome, Milan, Bari, Salerno, Turin and Modena. The cleaning process (i.e., the service provided by laundries) is performed inside the warehouse as an internal service. Real-world locations for the six stores and central warehouse are modelled using GIS to simulate realistic logistics, with internal laundry processing defined by a triangular distribution (1, 2, 3 hours). The model assumes unconstrained sales staff and allocates one truck per store for special occasion items used once per rental.

The customer represented in the supply chain is configured to have different behaviours. Based on a prior study by Quadras et al. (2025) on customer behaviour in fashion rentals, it was possible to identify two primary preferences that can influence attitudes and, consequently, the adoption of fashion rentals as opposed to traditional clothing purchases: enjoyment and sustainability factors. Two main customer typologies were derived from these two factors, they are:

- Enjoyment-driven: this customer type values the overall experience and enjoyment of renting fashion. They care about a smooth service (e.g., no waiting times).
- Sustainability-driven: this customer type chooses renting as an ethical and sustainable lifestyle decision. They care about reducing the environmental footprint.

The two customer typologies are modelled as agent types within the model, and they decide whether to rent an item based on their preference factors. The enjoyment-driven customer decides to rent or buy based on the availability of the item. If the item is available in the store, the

customer will rent. If it is not available for renting, the customer will buy the item. The sustainability-driven customer decides to rent or buy based on the sustainability factor of the item, as expressed in equation (1). Equation (1) compares the average of aggregate emissions of the item category C at the store K. If the client perceives that renting the item is more sustainable than buying it, the sustainability-driven customer will rent, otherwise he will buy the item.

$$\frac{\sum_{p=0}^{P_{CK}} \xi_{p,c,k}^{agg}}{P_{CK}} < \xi_c^{buy} \quad (1)$$

The customer renting rate (parameter $\boldsymbol{\lambda_0}$ in Table 1) is one per two months at the simulation start. However, the return rate is modelled to account the customer's satisfaction from the rental experience. To incorporate the satisfaction state into the customer's behavioural dynamics, the transition frequency is modelled using a stochastic intensity function. In this framework, the baseline return rate λ_0 is modulated by the latent satisfaction variable $S(t)$ through an exponential transformation, as presented in Equation (2). This formulation ensures that the rate remains strictly positive $(\lambda(t) > 0)$ while quantifying the elasticity of retention relative to past experiences.

$$\lambda(t) = \lambda_0 e^{S(t)} \quad (2)$$

The experience value of each customer is between -1 and 1. An experience value of -1 means the customer is unsatisfied, while an experience value of 1 means the customer is satisfied. Every time a customer rents an item the experience value is changed. In the model, the newest experiences have greater intensity compared to the more antique ones to simulate the memory loss. This event is modelled as presented in Equation (3), that represents a time-dependent stochastic accumulation where the current satisfaction level $S(t)$ is the sum of all past experiences E_i, each individually discounted by an exponential decay function. The term $(t - t_i)$ calculates the temporal distance between the present moment and each past event, ensuring that as time progresses, the weight of older experiences diminishes toward zero. The decay coefficient β works as a sensitivity parameter: a higher β creates a "short-term memory" effect where only the most recent events influence the agent's state, whereas a lower β allows historical experiences to persist longer. The model is based on the Hawkes process (Hawkes, 1971), where the current state of a system is an accumulation of weighted past events, the Ebbinghaus's forgetting curve (Averell & Heathcote, 2011), which states that memory retention declines at an exponential rate, and the exponentially weighted moving average (Hunter, 1986), to monitor processes while prioritizing recent data.

$$S(t) = \sum_{i=0}^{I} E_i e^{-\beta(t-t_i)} \quad (3)$$

New customers are assigned types randomly (50%) or inherit the type of their referrer via Word of Mouth (WoM).

To address RQ2, six scenarios vary rental duration (4 or 8 days), transport frequency (1 or 2 weekly), and truck size (small or big). These configurations explore trade-offs: longer rentals improve sustainability but increase waiting times, while higher transport frequency enhances customer enjoyment through faster delivery at the cost of higher CO2 emissions. The scenario configuration is summarized in Table 2.

Table 2: Scenarios configuration

Scenario	Rental period share [4/8 days]	Transport frequency [per week]	Transport type
1	50%/50%	2	Small truck
2	50%/50%	1	Big truck
3	80%/20%	2	Small truck
4	80%/20%	1	Big truck
5	20%/80%	2	Small truck
6	20%/80%	1	Big truck

To evaluate scenario impacts and address RQ2, four KPIs are compared. PSS performance is assessed via overall satisfaction and the share of renting versus buying customers. Sustainability is measured through monthly and aggregate CO_2 emissions derived from production, transport, and laundry activities. These metrics determine how supply chain configurations influence sustainability when behavioural factors are integrated. The simulation time is two years.

RESULTS AND DISCUSSION

Regarding the overall satisfaction over the simulation time for all scenarios, the results are shown in Figure 2. As the results show, after about one year, there is a decline in overall satisfaction for all scenarios. For scenario 3 the decline of satisfaction starts at the latest. The scenarios with two small trucks receive a higher mean overall satisfaction and a higher final value for overall satisfaction. Moreover, as Figure shows, these scenarios achieve higher satisfaction values for a longer time.

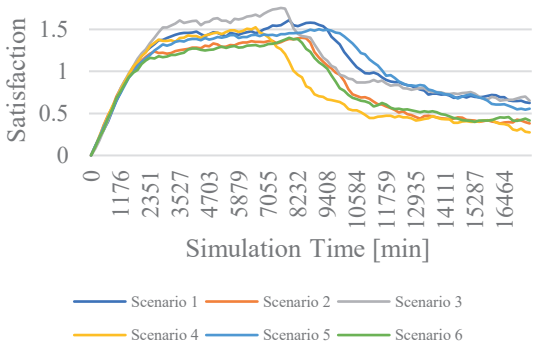

Figure 2: Evolution of satisfaction KPI of each simulation scenario over two years

Regarding the share of renting and buying customers, there is a difference in the behaviour of the two customer types (Figure 3 and Figure 4). In the scenarios with higher transport frequency (scenarios 1, 3, and 5),

the share of renting for the enjoyment-driven customer is higher. While, as expected, the share of renting among the sustainability-driven customers is lower in these scenarios.

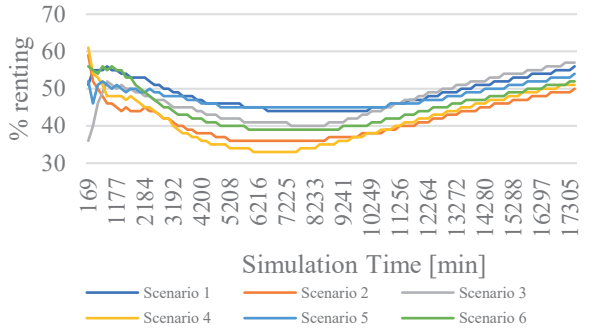

Figure 3: Share of renting of enjoyment-driven customer

The results for the mean monthly emissions for renting, in scenario 5, achieve the lowest value (1195 CO_2), while the mean monthly emissions for renting in scenario 3 achieve the highest value (2346 CO_2) compared to the other scenarios. Moreover, in scenarios 1, 2, 3 and 4, a higher frequency of transports increases the monthly emissions for renting by 6% (scenarios 1, 2) and 12% (scenarios 3, 4). While in scenario 5 and 6 a higher frequency of transports decreases the monthly emissions for renting by 38%. This shows that in scenarios with a longer period of renting the long renting period has a higher impact on reducing the monthly emissions for renting than the transport frequency.

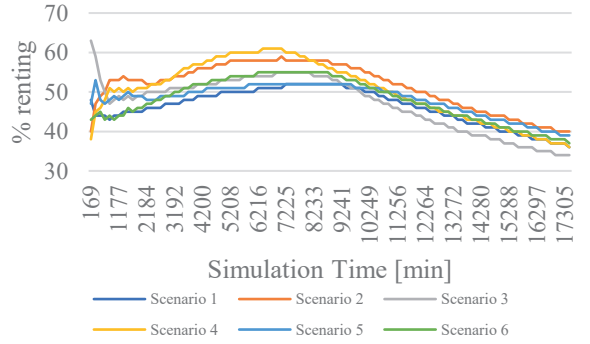

Figure 4: Share of renting of sustainability-driven customer

Comparing the mean monthly emissions for renting and then ones for buying, monthly emissions for renting are higher than those for buying in the first year, then, starting from the middle of the simulation period, monthly emissions for renting start to get lower, as shown in Figure 5. This is expected since the overall satisfaction for renting starts decreasing at the end of the first year, meaning fewer people is choosing the rental system instead of traditional purchase. In terms of average values, the mean monthly emissions for renting in scenario 5 are the lowest compared to the other scenarios. They are about 37% lower than the emissions for buying. However, this is the only scenario where the monthly emissions of renting are lower.

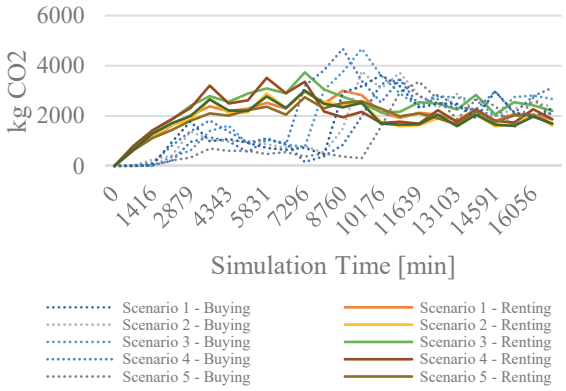

Figure 5: Monthly emissions KPIs of each simulation scenario over two years

Regarding the aggregate emissions for renting and buying (Figure 6) there is just one scenario, where the aggregate emissions for renting are lower than for buying (scenario 4). However, the difference is small (1%). For all other scenarios the aggregate emissions for buying are lower than for renting. The highest variation is achieved by scenario 5 (58%). Regarding the aggregate emissions per store, the store in Modena was found to have the lowest aggregate emissions for all scenarios (mean: 469 CO_2), while the store in Bari has the highest aggregate emissions for all scenarios (mean: 11435 CO_2), followed by the store in Salerno (mean: 10369 CO_2). This can be explained by the distance of the stores to the warehouse, which is based in Modena.

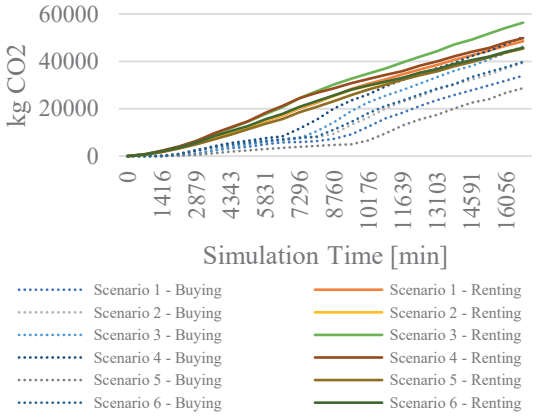

Figure 6: Aggregate emissions KPIs of each simulation scenario over two years

However, while the aggregate results suggest that buying generally leads to lower emissions compared to renting in most scenarios, a temporal analysis of the simulation reveals an important dynamic trend. Specifically, emissions associated with the buying model show a consistent increase from the midpoint of the simulation onwards. This trend coincides with a decline in user satisfaction with the renting model, which in turn drives a higher adoption of traditional purchase behavior. Although this shift is not fully captured within the simulation time horizon, it suggests that extending the simulation over a longer period could potentially alter the overall outcomes. In particular, a continued increase in buying adoption may lead to a reversal of the observed

results, with renting becoming comparatively more sustainable in the long term. This highlights the importance of considering behavioral feedback loops and long-term adoption dynamics when evaluating the environmental impact of alternative consumption models.

CONCLUSION AND OUTLOOK

This study addressed the need to incorporate behavioural dimensions into fashion renting decision-making by developing a simulation model in AnyLogic that integrates these factors into sustainability performance analysis.

Theoretically, this extends decision support system literature by demonstrating how behavioural variables can be systematically embedded to reflect realistic system dynamics (RQ1). Customers preferences and their satisfaction clearly influence the adoption of the renting system and the overall performance. The results indicate that fashion renting is not inherently sustainable and often performs worse than traditional sales (RQ2). However, the findings indicate that the environmental advantage of buying may be transient and dependent on short-term system simulation. When accounting for longer-term behavioural adaptation, the renting model could potentially outperform buying in terms of CO2 emissions.

Practically, the study provides a decision supporting tool for companies to assess the environmental performance of their fashion renting systems while also considering customer behaviour and their overall satisfaction level. The tool can help companies in configuring their rental system to achieve sustainable fashion renting supply chains. Longer rental periods with frequent small-truck transport proved to perform better in achieving realistic sustainability goals, suggesting the variability of results due to the renting system configuration, although this depends heavily on customer adoption and behaviour.

Despite its contributions, this study has some limitations. Behavioural factors are modelled based on assumed and aggregated patterns, which may not fully capture the complexity and heterogeneity of real-world user behaviour. In practice, customer typologies are likely to be more nuanced, as hybrid profiles that combine multiple decision drivers. Also, only two of the most recurrent behavioural factors were included in the developed model. Moreover, the simulation is conducted over a limited time horizon, which constrains the ability to fully observe long-term system dynamics.

Future research could validate the proposed customer typologies using empirical data and extend the model to include more realistic dynamic behaviour. Additionally, exploring other supply chain configurations (including decentralized warehouses, online shops, and local distribution strategies) could be interesting to enrich findings related to the sustainability of fashion renting systems. Expanding the analysis to include economic dimensions would also provide a more comprehensive evaluation of the viability of fashion renting systems.

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