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Simplified flood evacuation simulation in outdoor built environments. Preliminary comparison between setupbased generic software and custom simulator

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Highlights.

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Enrico Quagliarini¹, Gabriele Bernardini^{1,*}, Guido Romano

Abstract. Floods are among the most destructive sudden disaster affecting worldwide communities and society. In such extremely dangerous circumstance, pedestrians can be forced to evacuate the affected areas thus exposing them to multiple risks. Therefore, outdoor built environment flood risks analyses should be performed through rapid, easy, and sustainable tools to speed up the risk assessment for safety measures. To this end, custom evacuation simulators have been developed, but are generally used in research activities, not user-friendly, and need high-level training. On the contrary, generic (e.g. commercial) software tools seem to be more suitable for low-trained technicians but should be modified to include human behaviors effects, especially considering the evacuation, when people's peculiar choices depend on interactions with floodwaters and built environment layout/composing elements. This work tries to evaluate simulation differences between a custom simulator and a generic one with a specific setup to include main peculiar behaviors (no-code modifications). The chosen simulators are based on the same microscopic approach, and applied to an idealized literature-based outdoor scenario. Simulation outcomes are compared together and with real-world data. Results show acceptable differences when applying the generic simulator with proper setup, thus moving towards a promising use also by low-trained technicians.

Keyword. Urban flood; flood evacuation; pedestrians' evacuation; behavioral model; social force model; evacuation simulation; urban built environment; risk assessment.

1. Introduction

According to the UNDRR, "a sudden-onset disaster is one triggered by a hazardous event that emerges quickly or unexpectedly"¹. Between them, worldwide, floods are the most common and

¹ https://www.undrr.org/terminology/disaster (last access 29/10/2021)

devastating threats for our cities and society, affecting each year more individuals than any other
disaster (European Commission, 2017; Gu, 2019; Young and Jorge Papini, 2020). Thus, detailed yet
quick analyses and soluti devastating threats for our cities and society, affecting each year more individuals than any other disaster (European Commission, 2017; Gu, 2019; Young and Jorge Papini, 2020). Thus, detailed yet quick analyses and soluti devastating threats for our cities and society, affecting each year more individuals than any other disaster (European Commission, 2017; Gu, 2019; Young and Jorge Papini, 2020). Thus, detailed yet quick analyses and soluti 1 $\frac{2}{3}$ disaster (European Commission, 2017; Gu, 2019; Young and Jorge Papini, 2020). Thus, detailed yet $\frac{3}{2}$ $\frac{4}{1}$ existences and solutions are n 5 quick analyses and solutions are no

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quick analyses and soluti disaster (European Commission, 2017; Gui, 2019; Young and Jorge Papini, 2020). Thus, detailed yet
quick analyses and solutions are necessary to deal with such type of emergencies.
Previous works on flood risk assessment in quick analyses and solutions are necessary to deal with sueh type of emergeneies.
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Jammassri and Toda, 2018; Li et al., Previous works on 11000 risk assessment in outdoor spaces (Bernardini et al., 2017); Fan et al., 2015; Jamrussri and Toda, 2018; Li et al., 2019; Matsuo et al., 2011; Najafi et al., 2012; Paquier et al., 2015; Piyumi et al Jammussri and 10da, 2018; Lietal, 2019; Matsuo ctal., 2011; Najafi et al., 2021; Paquer et al., 2013;
Piyumi et al., 2021) pointed out the necessity of simulation tools for: (1) risk assessment and
mitigation strategies ev Pryumi ct al., 2021) pointed out the necessity of simulation tools for: (1) risk assessment and
intitigation strategies evaluation (e.g. rescuers' actions management, emergency planning, early
warning systems); and (2) mitigation strategies evaluation (e.g. rescuers actions management, emergency pianning, early
warning systems); and (2) interventions on the architectural spaces and facilities (e.g. drainage and
floodwater storage systems warning systems); and (2) interventions on the architectural spaces and facilities (e.g. dramage and
floodwater storage systems in BE, handrails and platforms to support people moving in the open
spaces). These simulators Thodwater storage systems in BF, handrails and platforms to support people moving in the open
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conditions highly affect casualti spaces). These simulators should include the representation of the evacuation process in flood
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conditions highly affect cas conditions, since the interactions between the pedestrians, the surrounding BE and the Hoodwater
conditions highly affect casualties in such first disaster phases (Ashley and Ashley, 2008; Bernardini
et al., 2017b; Dias e conditions highly affect casualties in sulen link disaster phases (Ashley and Ashley, 2008; Bernardim
et al., 2017b; Dias et al., 2021; Samany et al., 2021; Shirvani et al., 2020; Takagi et al., 2016). Thus,
the represent Previous works on flood risk assessment in outdoor spaces (Bernardini et al., 2017b; Fan et al., 2018; 8 ⁹ Iamps I and Toda $2018 \cdot 1$ i.et al. 10 vannusbirund Toda, 2010, Erotan 11 12 Piyumi et al., 2021) pointed out 13 14 mitigation strategies evaluation (15 15 16 17 warning systems); and (2) interver 18 19 floodwater storage systems in BE, handrails and platforms to support people moving in the open 20 20 contract con 21 and \mathbf{r} and \mathbf{r} and \mathbf{r} and \mathbf{r} and \mathbf{r} and \mathbf{r} 22 spaces). These simulators should 23 24 conditions, since the interactions between the pedestrians, the surrounding BE and the floodwater 25 25 and 26 an 26 conditions highly offect equiplies 27 Conditions inginy arrest casualities 28 29 et al., 2017b; Dias et al., 2021; Samany et al., 2021; Shirvani et al., 2020; Takagi et al., 2016). Thus, 30 30 $\frac{31}{100}$ the representation of the human formula 32 and representation of the number is 33 34 dynamic issues) and peculiar beh 35 $\frac{36}{37}$ preliminarily evaluations of the hosted community's reaction to the disaster and the effectiveness of $37 \quad \frac{1}{2}$ 38 39 emergency response actions (Bel 40 ⁴¹ Jamrussri and Toda, 2018; Jia et al., 2016; Kolen and van Gelder, 2018; Mignot et al., 2019).

et al., 2017b; Dias et al., 2021; Samany et al., 2021; Shirvani et al., 2020; 1 akagi et al., 2016). Thus,
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dynamic issues the representation of the human factor in terms of presences (e.g. by also including spatiotemporal
dynamic issues) and peculiar behaviors before and during the flood, assume a paramount role in
preliminarily evaluations dynamic issues) and peculiar behaviors before and during the flood, assume a paramount ro
preliminarily evaluations of the hosted community's reaction to the disaster and the effectivene
emergency response actions (Bernar behaviors before and during the flood, assume a paramount role in

hosted community's reaction to the disaster and the effectiveness of

Bernardini et al., 2017b; Bodoque et al., 2016; Dai et al., 2020;

et al., 2016; Kol prelimmarily evaluations of the hosted community's reaction to the disaster and the effectiveness of
emergency response actions (Bernardini et al., 2017b; Bodoque et al., 2016; Dai et al., 2020;
Jammussri and Toda, 2018; $\begin{array}{lll} 60 & \text{speed } v_i. \end{array}$ 43 44 According to previous works on p 45 46 et al., 2017a; Ishigaki et al., 2008 47 48 most significant effects in the evac 49 most significant creets in the cytae 50 51 and speed v_f [m/s]). Firstly, it affect 52 53 2017a) traces the minimum expe 54 -337.4 , -447.4 -447.4 -447.4 55 (a) 1 (b) $\frac{1}{2}$ (c) $\frac{1}{2}$ (c) 56 gravitational acceleration [m⁻/s]) 57 58 estimation, and so in the evacuation timing assessment. The higher D_f and v_f , the lower the evacuation 59 61 speed v_i .

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v_i = 0.52 \left(\frac{p_f v_f^2}{g} + \frac{p_f^2}{2} \right)^{-0.11} \tag{1}
$$

 $v_i = 0.52 \left(\frac{D_f v_f^2}{g} + \frac{D_f^2}{2} \right)^{-0.11}$ (1)
Secondly, critical D_f and v_f induce human body instability, provoking pedestrians' evacuation stop
and serious threats because of buoyancy phenomena or body failure (C $v_i = 0.52 \left(\frac{D_f v y_i^2}{g} + \frac{D_f^2}{2} \right)^{-0.11}$ (1)
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and serious threats because of buoyancy phenomena or body failure ($v_i = 0.52 \left(\frac{D_f v_f^2}{g} + \frac{D_f^2}{2} \right)^{-0.11}$ (1)
Secondly, critical D_f and v_j induce human body instability, provoking pedestrians' evacuation stop
and serious threats because of buoyancy phenomena or body failure (C ans' evacuation stop
Shand, T.D.Blacka,
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ans walking through $v_l = 0.52 \left(\frac{D_f v_f^2}{g} + \frac{D_f^2}{2} \right)^{-0.11}$ (1)
Secondly, critical D_f and v_f induce human body instability, provoking pedestrians' evacuation stop
and serious threats because of buoyancy phenomena or body failure (C $v_l = 0.52 \left(\frac{p_f v_f^2}{g} + \frac{p_f^2}{2} \right)^{-0.11}$ (1)
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and serious threats because of buoyancy phenomena or body failur $3 \qquad$ Secondly critical D_{ϵ} and veinduce $\frac{4}{4}$ becoming, chircui D_f and v_f made. 5 (a. 1300).
1905 - Johann John Barn, politik eta alderdizionen eta alderdizionen eta alderdizionen eta alderdizionen eta a 6 and serious threats because of bud 7 ⁸ 2010) General consolidated thresh $9 - 11$ 10 (a) 11 (a) 12 (a) 13 11 in case of still water, $D\geq 1.2$ m, whi

 $v_i = 0.52 \left(\frac{D_f v_y^2}{g} + \frac{D_f^2}{2} \right)^{-0.11}$ (1)
Secondly, critical D_f and y_i induce human body instability, provoking pedestrians' evacuation stop
and serious threats because of buoyancy phenomena or body failure (C $v_i = 0.52 \left(\frac{p_i v_f^2}{a} + \frac{p_f^2}{2}\right)^{-0.11}$ (1)
Secondly, critical D_f and v_f induce human body instability, provoking pedestrians' evacuation stop
and serious threats because of buoyancy phenomena or body failure (Cox $v_i = 0.52 \left(\frac{\rho_f v_f^2}{g} + \frac{\rho_f^2}{2} \right)^{-0.11}$ (1)
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and serious threats because of buoyancy phenomena or body failur Secondly, critical D_f and v_f induce human body instability, provoking pedestrians' evacuation
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2010). General consolidated thresh Secondly, entical *Df* and *y* induce human body instability, provoking pedestrians' evacuation stop
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2010). General consolidate and scrious threats because of buoyaney phenomena or body failure (Cox and Shand, 1.1.Biacka, 2010). General consolidated thresholds to these problems refer to $D_f^*v_f \ge 1.2$ m²/s or $v_f \ge 3.0$ m/s, and, in ease of still $^{13}_{14}$ Moreover, the perception of unmovable obstacles as safe elements for pedestrians walking through 14 15 θ is denotion in an end on DE above. 16 1100 dividers in an urban DE can a 17 18 (Bernardini et al., 2017b). Indeed, pedestrians prefer moving towards and near walls and fences 19 20 $($ (proformed distance of about 1_m to21 (preferred distance of about THT to 22 and 22 an 23 and handle on them while walking.
24

2010). General consolidated thresholds to these problems refer to $D_f^2 \gamma/21.2$ m/s or $\nu/23.9$ ms, and, in case of still water, $D \ge 1.2$ m, which provokes buoyancy.
Moreover, the perception of unmovable obstacles as saf m case of still water, $D \ge 1.2m$, which provokes buoyancy.

Moreover, the perception of unmovable obstacles as safe elements for pedestrians walking through

floodwaters in an urban BE can alter the pedestrians' trajecto Morcover, the perception of unmovable obstactes as sate elements for peacstrans watking through
floodwaters in an urban BE can alter the pedestrians' trajectories because of attraction phenomena
(preferred distance of abou Thoodwaters in an urban BE can after the pedesthrans' trajectories because of attraction phenomena
(Bernardini et al., 2017b). Indeed, pedestrians prefer moving towards and near walls and fences
(preferred distance of abou (Bernardmi et al., 2017b). Indeed, pedestrians prefer moving towards and near walls and fences
(preferred distance of about 1m to 2m, with an experimental considered limit of 3m) to gain support
and handle on them while wa (preferred distance of about 1m to 2m, with an experimental considered limit of 3m) to gain support
and handle on then while walking.
In view of the above, the analysis of emergency conditions through simulation software s In view of the above, the analysis of emergency conditions through simulation software should
involve the above, the analysis of emergency conditions through simulation software should
involve the aboption of microscopic m In view of the above, the analysis of emergency conditions through simulation software should
involve the adoption of microscopic models rather than macroscopic approaches, since they are able
to represent the specific ind mvoive the adoption of microscopic models rather than macroscopic approaches, since they are able
to represent the specific individual-scale interactions in the evacuation process (Jebrane et al., 2019).
Such a microscopic functionality, and interoperability that could slow down (or impede) crucial analyses for the method of the method of the matching methodologies (e.g. cellular automata, social force models) (Bernardini et al., 2017b; Li e Such a microscopic approach has been adopted by several flood evacuation simulators proposed
according to different modelling methodologies (e.g. cellular automata, social force models)
(Bernardini et al., 2017b; Li et al. according to different modelling methodologies (e.g. cellular automata, social force models)
(Bernardini et al., 2017b; Li et al., 2019; Matsuo et al., 2011; Shirvani et al., 2020), thus developing
eustom models for resear 25 In view of the above the analys 26 and $\frac{1}{26}$ and $\frac{1}{26}$ are $\frac{1}{26}$ and $\frac{1}{26}$ 27 28 mvolve the adoption of microscop 29 $^{30}_{31}$ to represent the specific individual-scale interactions in the evacuation process (Jebrane et al., 2019). 31 $\frac{32}{9}$ $\frac{1}{9}$ $\frac{1}{9}$ $\frac{1}{10}$ 33 Such a microscopic approach has 34 35 according to different modelling methodologies (e.g. cellular automata, social force models) 36 37 (Domending et al. $2017k$, Liet al. 38 (Definatum et al., 20170, Li et al., 39 40 custom models for researches purp 41 42 nedestrians' behaviors in flooded 43 Pedestrians centeriors in ricoded 44 45 comparisons with real-world dat 46 47 (Bernardini et al. 2017b: Li et al. 48 (Figure 2022 1: 2014) = 22 1: 22 1: 22 1: 22 1: 22 1: 22 1: 22 1: 22 1: 22 1: 22 1: 22 1: 22 1: 2

(Bernardini et al., 2017b; Li et al., 2019; Matsuo et al., 2011; Shirvani et al., 2020), thus developing
eustom models for researches purposes. They try to effectively represent the aforementioned peculiar
pedestrians' beh 49 50 However, such custom software is 51 52 functionality, and interoperability that could slow down (or impede) crucial analyses for the risk 53 and $\frac{1}{2}$ 54 55 assessment, especially considerin 56 57 Authorities technicians, who can have a low training level on the matter. Generic evacuation 58 58 59 simulation tools on the contrary r 60 simulation tools, on the contrary, 1

widely implemented in more user-friendly software, especially considering commercial ones. They
are oriented towards general-purpose evacuation simulation, or towards fire scenarios, and use
behavioral and motion quantitie widely implemented in more user-friendly software, especially considering commercial ones. They are oriented towards general-purpose evacuation simulation, or towards fire scenarios, and use behavioral and motion quantitie widely implemented in more user-friendly software, especially considering commercial ones. They
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behavioral and motion quantitie wheely mplemented in more user-finendly software, especially considering commercial ones. They
are oriented towards general-purpose evacuation simulation, or towards fire scenarios, and use
behavioral and motion quantities are onented towards general-purpose evacuation simulation, or towards tire secnarios, and use
behavioral and motion quantities from related databases (Bosina and Weidmann, 2017; Ronchi, 2020;
Shi et al., 2009). Their gener behavioral and motion quantities from related databases (Bosma and Weidmann, 2017; Ronen, 2020;
Shi et al., 2009). Their general verification and validation process has been provided according to
standard testing condition Shi et al., 2009). Their general vertication and valuation process has been provided according to standard testing conditions (Ronchi et al., 2013a). Nevertheless, generic software needs adequate modifications to represent standard testing conditions (Konch et al., 2013a). Neverthecess, generic software necess adequate
modifications to represent flood-related behaviors. To this end, adopting a specific software setup
can ensure a quick and s modifications to represent lood-related behaviors. To this end, adopting a specific software setup
can ensure a quick and standard-based software application, thus avoiding complexity-increasing
operations on the source co can ensure a quick and standard-based software application, thus avoiding complexity-increasing
operations on the source code or the implementation of dedicated plug-ins and additional tools.
Meanwhile, reliability analyse operations on the source code or the implementation of deciteated plug-ins and additional tools.
Meanwhile, reliability analyses of such a setup-based generic model should be provided (Bernardini
et al., 2017b; Li et al., Meanwhite, rehability analyses of suen a setup-based generic model should be provided (Bernardini

et al., 2017b; Li et al., 2019; Ronehi, 2020; Ronehi et al., 2013a). Comparisons with real-world data

could be performed t et al., 2017b; Li et al., 2019; Ronchi, 2020; Ronchi et al., 2013a). Comparisons with real-world data
could be performed to this end. Simulation results of a setup-based generic model could be also
compared to custom and f 1 $\frac{2}{3}$ are oriented towards general-purpose evacuation simulation, or towards fire scenarios, and use 3 $\frac{4}{4}$ hological and motion quantities for 5 behavioral and motion quantities in $6\overline{6}$ ⁷ Shi et al., 2009). Their general verification and validation process has been provided according to 8 9 standard testing conditions (R one 10 standard testing conditions (respectively 11 12 modifications to represent flood-r 13 $^{14}_{15}$ can ensure a quick and standard-based software application, thus avoiding complexity-increasing 15 16 17 operations on the source code or 18 19 Meanwhile, reliability analyses of such a setup-based generic model should be provided (Bernardini 20 20 and 20 an 21 $(1.20171 \times 1.4 \times 1.2010 \times R)$ 22 **CL al., 20170, LI et al., 2019, NOIIC** 23 24 could be performed to this end. Simulation results of a setup-based generic model could be also 25 25 and \sim 25 and \sim 25 and \sim 25 and 26 and 27 and 27 and 27 and 27 a 26 compared to quatern and flood ded 27 Compared to castom and nobe-dee 28 29 defined as a fair comparison, because of the peculiarities of the modelling logics, such comparisons 30 30 $\frac{31}{2}$ can roughly and preliminarily evalu 32 can reaging and premium in σ 33 and the set of the
Set of the set of the 34 outputs typical of the considered 35 36 pedestrians and unmovable obstacles) in different approaches. $37 \quad \frac{1}{2}$

could be performed to this end. Simulation results of a sctup-based generic model could be also
compared to custom and flood-dedicated simulators. Although this kind of analysis cannot be always
defined as a fair compariso comparca to custom and Hood-dedreated simulators. Although this kind of analysis cannot be always
defined as a fair comparison, because of the peculiarities of the modelling logics, such comparisons
can roughly and prelimi defined as a fair comparison, because of the peculiarities of the modelling logies, such comparisons
can roughly and preliminarily evaluate possible differences and behavioral uncertainties in simulation
outputs typical of can roughly and preliminarily evaluate possible differences and behavioral uncertainties in simulation
outputs typical of the considered disaster (e.g. evacuation timing, trends of distances between
pedestrians and unmovab outputs typical of the considered disaster (e.g. evacuation timing, trends of distances between
pedestrians and unmovable obstacles) in different approaches.
This work tries to compare the simulation results of two differe pedestrians and unmovable obstactes) in different approaches.
This work tries to compare the simulation results of two different microscopic software based on the
Social Force Model (SFM) approach (Helbing et al., 2000): a This work tries to compare the simulation results of two different microscopic software based on the Social Force Model (SFM) approach (Helbing et al., 2000): a custom flood evacuation simulator (Flooding Pedestrians' Evac 38 TH: 1.1. 1.1. 39 THIS WORK THES TO COMPATE THE SITE 40 41 Social Force Model (SFM) approach (Helbing et al., 2000): a custom flood evacuation simulator 42 43
(Electing Dedectries Lynevation 44 (Probling Political Evacuation 45 46 preliminarily validated according to experimental data for flood evacuation purposes (Bernardini et 47 47 48 al 2017b); and a generic (comp 49 and $201/6$, and a generic (comm 50 51 analysis (MassMotion Guide, 202 52 $^{53}_{54}$ represent main man-floodwaters and man-built environment behaviors. 54

55 56 10 this end, the work and the pap 57 58 firstly traces the criteria for generic software setup and comparisons with custom tools and real-world 59 60 61 add according to four main phases

human flood-affected evacuation behaviors in outdoor in a generic simulator (Section 2.1). Then, a scenario is selected according to previous works (Bernardini et al., 2017b) to apply the setup-based generic simulator and human flood-affected evacuation behaviors in outdoor in a generic simulator (Section 2.1). Then, a scenario is selected according to previous works (Bernardini et al., 2017b) to apply the setup-based generic simulator and human flood-affected evacuation behaviors in outdoor in a generic simulator (Section 2.1). Then, a scenario is selected according to previous works (Bernardini et al., 2017b) to apply the setup-based generic simulator and human flood-affected evacuation behaviors in outdoor in a generic simulator (Section 2.1). Then, a scenario is selected according to previous works (Bernardini et al., 2017b) to apply the setup-based generic simulator and human flood-affected evacuation behaviors in outdoor in a generic simulator (Section 2.1). Then, a scenario is selected according to previous works (Bernardini et al., 2017b) to apply the setup-based generic simulator and human flood-affected evacuation behaviors in outdoor in a generic simulator (Section 2.1). Then, a scenario is selected according to previous works (Bernardini et al., 2017b) to apply the setup-based generic simulator and human flood-affected evacuation behaviors in outdoor in a generic simulator (Section 2.1). Then, a
scenario is selected according to previous works (Bernardini et al., 2017b) to apply the setup-based
generic simulator and human flood-affected evacuation behaviors in outdoor in a generic simulator (Section 2.1). Then, a scenario is selected according to previous works (Bemardini et al., 2017b) to apply the setup-based generic simulator and t human flood-affected evacuation behaviors in outdoor in a generic simulator (Section 2.1). Then, a scenario is selected according to previous works (Bernardini et al., 2017b) to apply the setup-based generic simulator and numan Hood-affected evacuation behaviors in outdoor in a generic simulator (Section 2.1). Then, a
scenario is selected according to previous works (Bernardini et al., 2017b) to apply the setup-based
generic simulator and t scenario is selected according to previous works (Bernardini et al., 2017b) to apply the setup-based
generic simulator and the custom one (Section 2.2). This scenario is quite simple since it is a linear
and flat pathway, genere simulator and the custom one (Section 2.2). This secnario is quite simple since it is a linear
and flat pathway, representing a common outdoor BE such as a street, and concerns stationary flood
conditions where smal and rat patnway, representing a common outdoor BE such as a street, and concerns stationary nood
conditions where small compact groups of pedestrians are evacuating. Nevertheless, as in the
aforementioned general aims of s condutions where small compact groups of pedestrians are evacuating. Neverthetess, as in the aforementioned general aims of standard testing conditions for verification and validation of evacuation simulators, if the compa aforementioned general aims of standard testing conditions for vertification and valuation of
evacuation simulators, if the comparison is not effective in such a simple scenario, more sensible
differences between the simul evacuation simulators, if the comparison is not effective in such a simple scenario, m
differences between the simulators will surely appear in more complex outdoor BE o
Different setup solutions of the generic simulator a can alter the expected simulation outcomes with respect to the custom s

real-world data (Section 2.3). Simulation results of the two software are

significant outputs to be evaluated for the flood evacuation, and addition world data (Section 2.3). Simulation results of the two software are compared through the main
inficant outputs to be evaluated for the flood evacuation, and additional analyses concerning real-
dd data are provided for th Significant outputs to be evaluated for the flood evacuation, and additional analyses concerning real-
world data are provided for the setup-based generic simulator (Section 2.4). Results are organized
comparing outputs of world data are provided for the setup-based generic simulator (Section 2.4). Results are organized
comparing outputs of the generic and custom simulators (Sections 3.1 to 3.3), then the comparison is
extended to real-world 1 ² scenario is selected according to previous works (Bernardini et al., 2017b) to apply the setup-based 3 $\frac{4}{3}$ conomic simulator and the system. 5 generic simulator and the custom $6\overline{6}$ and flat pathway, representing a common outdoor BE such as a street, and concerns stationary flood 8 8 ⁹ conditions where small compact 10 conditions where small compact 11 12 aforementioned general aims of 13 ¹⁴ evacuation simulators, if the comparison is not effective in such a simple scenario, more sensible 15 15 16 17 differences between the simulator 18 $^{19}_{20}$ Different setup solutions of the generic simulator are tested, thus allowing us to check the factors that 20 and 1 control 20 co 21 \cdots then the concept defined the \cdots 22 Can alter the expected simulation 23 ²⁴ real-world data (Section 2.3). Simulation results of the two software are compared through the main ²⁵ 25 and 26 an 26 cignificant outputs to be evaluated 27 Significant bulpuls to be evaluated 28 29 world data are provided for the setup-based generic simulator (Section 2.4). Results are organized 30 30 $\frac{31}{\text{comparing outmits of the generic}}$ 32 Comparing carpeter of the generic to 33 34 extended to real-world data (Secti 35 $\frac{36}{37}$ discussed (Section 3.5). 37

41 **M**_{othode} 42 $2.$ Mcmous

45 2.1. Software setu

comparing outputs of the generic and custom simulators (Sections 3.1 to 3.3), then the comparison is
extended to real-world data (Section 3.4). Finally, the generic simulator fittest setup is selected and
discussed (Secti extended to real-world data (Section 3.4). Finally, the generic simulator fittest setup is s
discussed (Section 3.5).

2. Methods

2.1. Software setup criteria to replicate human behavior

The quick setup of a generic sim **2. I. Software setup criteria to replicate human behaviors**
 2.1. Software setup criteria to replicate human behaviors

The quick setup of a generic simulator is based on the following main assumption, according to t **2. Methods**
2.1. Software setup criteria to replicate human behaviors
The quick setup of a generic simulator is based on the following main assumption, according to the
main behavioral drivers from the literature rev ⁴⁸ The quick setup of a generic simu 49 50 main behavioral drivers from the 51 main behavioral directs from the 52 53 advantages and implementation 54 $^{55}_{56}$ application are also discussed. 56 **Treatment in the contract of**

57 58 Concerning v_i , stationary Hoodwat 59 change over the simulation time. In this work, a unique area in terms of D_f and v_f is simulated, thus 61 61

creating a unique v_i value in the setup process, according to Equation1. Differences between v_i can
be assigned by most of the evacuation simulators in a rapid manner, as well as different typologies of
pedestrians ca creating a unique v_i value in the setup process, according to Equation1. Differences between v_i can
be assigned by most of the evacuation simulators in a rapid manner, as well as different typologies of
pedestrians ca creating a unique v_i value in the setup process, according to Equation1. Differences between v_i can be assigned by most of the evacuation simulators in a rapid manner, as well as different typologies of pedestrians ca creating a unique v_i value in the setup process, according to Equation1. Differences between v_i can be assigned by most of the evacuation simulators in a rapid manner, as well as different typologies of pedestrians ca creating a unique v_i value in the setup process, according to Equation1. Differences between v_i can be assigned by most of the evacuation simulators in a rapid manner, as well as different typologies of pedestrians ca creating a unique v_i value in the setup process, according to Equation1. Differences between v_i can
be assigned by most of the evacuation simulators in a rapid manner, as well as different typologies of
pedestrians ca ¹¹ assigned to describe low-medium floodwater levels, e.g. being $(D_f \cdot v_f^2)/g+D_f^2/2 \approx 0.01 \text{m}^3/\text{m}$. In a order the value of the value of the value of the value of m . In a value of the value of m and m are value of the value of m and m are va ercating a unique v_l value in the setup process, according to Equation1. Differences between v_l can
be assigned by most of the evacuation simulators in a rapid manner, as well as different typologies of
pedestrians ca creating a unique v_i value in the setup process, according to Equation1. Differences between v_i can
be assigned by most of the evacuation simulators in a rapid manner, as well as different typologies of
equestrians ca ereating a unique v_i value in the setup process, according to Equation1. Differences between v_i can
be assigned by most of the evacuation simulators in a rapid manner, as well as different typologies of
pedestrians ca ercating a unique v_i value in the setup process, according to Equation E. Differences between v_i can
be assigned by most of the evacuation simulators in a rapid manner, as well as different typologies of
pedestrians c be assugned by most of the evacuation simulators in a rapid manner, as well as different typologies of pedestrians can be ensured using, for example, a v_i distribution. In this work, according to the reference work (Ber pedestrians can be generally ereated to this end. Hence, the representation of pedestinans' speed
uncertainties can be ensured using, for example, a v_i distribution. In this work, according to the
reference work (Bernar the using, for example, a v_i distribution. In this work, according to the st al., 2017b), v_i in the range 0.85+0.05 m/s (Gaussian distribution) is dium floodwater levels, e.g. being $(D_f \cdot v_f^2)/g+D_f^2/2 \approx 0.01 \text{ m}^3/\text{$ reterence work (Bernardmi et al., 2017b), v_i in the range 0.85±0.05 m/s (claussian distribution) is
assigned to describe low-medium floodwater levels, e.g. being $(D_f \cdot v_f^2)/g + D_f^2/2 \approx 0.01 \text{m}^3/\text{m}$. In a
full-scale a assigned to deserthe low-medium Hoodwater levels, e.g. being (*D_f* 'v_f' J/g²+D_f' /2 ⁼0.01 m²/m. In a full-scale application scenario, the motion space can be divided into different areas (as for floors in ease 1 $\frac{2}{3}$ be assigned by most of the evacuation simulators in a rapid manner, as well as different typologies of 3 $\frac{4}{4}$ redections can be concretty and 5 peucontains can be generally crea $6\overline{6}$ m certainties can be ensured using, for example, a v_i distribution. In this work, according to the 8 9 reference work (Remardini et al. 10 reference work (Definitum of an, 12 assigned to describe low-medium 13 $^{14}_{15}$ full-scale application scenario, the motion space can be divided into different areas (as for floors in $\frac{15}{11}$ 16 17 case of building evacuation simula 18 19 floodwater level, hence a maximum (e.g. capped) motion speed v_i . Ideally, v_i can be also varied over 20 20 21 22 Simulation time to describe dynam

nul-scale application scenario, the motion space can be divided into different areas (as for floors in
case of building evacuation simulators (MassMotion Guide, 2020)), each of them having a specific
floodwater level, henc ease of building evacuation simulators (MassMotion Giude, 2020)), each of them having a specific
floodwater level, hence a maximum (e.g. capped) motion speed y_i . Ideally, y_i can be also varied over
simulation time to d Those oriental method into MassMotion 10.6². This simulation time also varied over simulation time to describe dynamic conditions in floodwaters spreading.
Non-critical conditions for human body stability are assumed in simulation time to describe dynamic conditions in noodwaters spreading.
Non-critical conditions for human body stability are assumed in this work. Indeed, it is considered
that the motion-process should be carried out in a 24 Non-critical conditions for human body stability are assumed in this work. Indeed, it is considered 25 25 and 26 an 26 that the motion process should be 27 that the motion-process should be 28 29 related pedestrians' stability can o 30 31 safe area in the simulated scenario 32 Sure area in the simulated second to

33 34 Finally, concerning the attraction 35 ³⁶ elements are imposed, since literature works noticed that pedestrians prefer to stay closer than about ³⁷ 37 **1** 38 a $\sqrt{2}$ and $\sqrt{2}$ and 39 **311 In any case (Bernardini et al.,** 40 41 along linear paths alongside the building walls/fences. 42

that the motion-process should be carried out in any ease before major unears due to hoodware-
related pedestrians' stability can occur (Opper et al., 2010). Thus, all the pedestrians can arrive in a
safe area in the simul desired and the scenario, and tests can focus on the motion tasks.

Elementated scenario, and tests can focus on the motion tasks.

Elementation towards unmovable obstacles, preferred distances pedestrians-

imposed, since sate area in the simulated sechario, and tests can locus on the motion tasks.
Finally, concerning the attraction towards unmovable obstacles, preferred distances pedestrians-
elements are imposed, since literature works no rmany, concerning the autaction towards uninovable obsactes, preterred distances peocstrans-
elements are imposed, since literature works noticed that pedestrians prefer to stay closer than about
3m in any case (Bermardin 43 44 **THESE CHIEFIA ALE IMPLEMENTED** 45 ⁴⁶ simulate the pedestrians' movement, thus being based on the same model approach of FlooPEDS. 47 48 American American the example 49 Appendix A resulter the overal 50 51 pedestrians' data and the scenario implementation. In particular, concerning the attraction towards 52 52 53 unmovable obstacles this work 54 **ANDROID COMMONS**, this work 55 56 alongside the buildings (MassMot

 60 ² Tests (randomly selected within the list of the validation scenarios in Section 2) were additionally carried out with
61 MassMotion 9.5.2.2 to compare results with the previous version and no differences were f 61 MassMotion 9.5.2.2 to compare results with the previous version and no differences were found.
62

2.2. Tested scenario

Exemployed according to Section 2.1) and Floor

Exemployed according to Section 2.1) and Floor

Exemployed according to Section 2.1) and Floor

Franco in the same typological scenario for comparison p 2.2. **Tested scenario**
The setup-based version of MassMotion (developed according to Section 2.1) and FlooPEDS
(Bernardini et al., 2017b) are applied to the same typological scenario for comparison purposes.
According to t 2.2. Tested scenario
The setup-based version of MassMotion (developed according to Section 2.1) and FlooPEDS
(Bernardini et al., 2017b) are applied to the same typological scenario for comparison purposes.
According to the 2.2. Tested scenario
The setup-based version of MassMotion (developed according to Section 2.1) and FlooPEDS
(Bernardini et al., 2017b) are applied to the same typological scenario for comparison purposes.
According to the **2.2.** Tested scenario
The sctup-based version of MassMotion (developed according to Section 2.1) and FlooPEDS
(Bernardini et al., 2017b) are applied to the same typological scenario for comparison purposes.
According to t **2.2. Tested scenario**
The setup-based version of MassMotion (developed according to Section 2.1) and FlooPEDS
(Bernardini et al., 2017b) are applied to the same typological scenario for comparison purposes.
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The setup-based version of MassMotion (developed according to Section 2.1) and FlooPEDS
(Bernardini et al., 2017b) are applied to the same typological scenario for comparison purposes.
According t 2.2. **Tested scenario**
The setup-based version of MassMotion (developed according to Section 2.1) and FlooPEDS
(Bernardini et al., 2017b) are applied to the same typological secnario for comparison purposes.
According to t **2.2.** Tested scenario
The setup-based version of MassMotion (developed according to Section 2.1) and FlooPEDS
(Bernardini et al., 2017b) are applied to the same typological scenario for comparison purposes.
According to t The setup-based version of MassMotion (developed according to Section 2.1)
(Bernardini et al., 2017b) are applied to the same typological scenario for comp
According to the previous FlooPEDS tests, this scenario is compose The scap cases version of stassistional (acvespos according to section 2.1) and floot EDS
(Bernardini et al., 2017b) are applied to the same typological scenario for comparison purposes.
According to the previous FlooPEDS (Bernardini et al., 2017b). The upplied to the althe typological secular of comparison parposes.
According to the previous FlooPEDS tests, this scenario is composed of a linear pathway having a
width of 17.6m and a length side starting to the previous Fristry team, this account is composed of a mean pairway naving a width of 17.6m and a length of about 87m, with a linear plano-altimetric profile and no internal crossroads³. Two continuous 3 The setup-based version of Mas 4 5 (Bernardini et al. 2017b) are any $6\qquad$ (Bernard in Section, 2017b) are approximately 7 8 According to the previous FlooPE 9 $_{11}^{10}$ width of 17.6m and a length of about 87m, with a linear plano-altimetric profile and no internal 11 12 13 π 13 13 13 crossroads². I wo continuous buil 14 15 pathway side. This configuration allows focusing on the pedestrians' elementary motion conditions, 16 F^{actor} 11 February 11 February 11 February 1 17 (a) α 1 (b) α 1 (c) α 1 (c) α 1 (c) α 18 Since constant Hoodwater condition 19 ²⁰ simple but critical layout in urban open spaces and it is also consistent with the IMO test 1 scheme ²¹ 21 **Example 1** and the contract of $\frac{1}{2}$ and the contract of $\frac{1}{2}$ 22 $(D - 1)$ (20121) 23 (Ronchi et al., 2013b).

attractions between the pedestrians between the square meters of outdom BE considered placed alongside the pathway, one on each pathway side. This configuration allows focusing on the pedestrians' elementary motion conditi erossoaus : Two continuous outrolligs are considered and also are particularly, one on each particular particular simple but critical layout in urban open spaces and it is also consistent with the IMO test 1 scheme simple pathway stoc. This coming transformation anows focusing on the periostical selenchary motion conditions,
since constant floodwater conditions are imposed⁴. In this sense, it is representative of a street for a
simple but since constant inotowater continuors are imposed. In ims sense, it is representative of a street for a
simple but critical layout in urban open spaces and it is also consistent with the IMO test 1 scheme
(Ronchi et al., 20 sense, it is representative of a street for a
so consistent with the IMO test 1 scheme
he original work about FlooPEDS tests
ring compact groups of 10 pedestrians per
the overlapped effects between the SFM
en the pedestria simple but critical layout in urban open spaces and it is also consistent with the IMO test 1 scheme
(Ronchi et al., 2013b).
The following general rules are applied according to the original work about FlooPEDS tests
(Bern (Konchi et al., 2013b).
The following general rules are applied according to the original work about FlooPEDS tests
(Bernardini et al., 2017b). Tests are carried out by considering compact groups of 10 pedestrians per
side The following general rules are applied according to the original work about PlooPEDS tests
(Bernardini et al., 2017b). Tests are carried out by considering compact groups of 10 pedestrians per
side starting the evacuation (Bernardini et al., 2017b). I ests are carried out by considering compact groups of 10 ped
side starting the evacuation at the same time, to point out the overlapped effects betwee
attractions between the pedestrians thems ²⁵ The following general rules are applied according to the original work about FlooPEDS tests ²⁶ 26 **26** 27 (Democratic interaction of 2017). The trace 28 (Definantin et al., 20170). Tests an 29 30 side starting the evacuation at the same time, to point out the overlapped effects between the SFM
31 31 32 structions between the nedestrian 33 attractions between the pedestrian 34 35 number of simulated pedestrians 36 37 nedestrians (coming from buildin 38 Processions (coming from content 39 40 conditions (LOS A, free circulation 41 ⁴² with previous works input data on pedestrians' densities (Samany et al., 2021; Shirvani et al., 2020). 43 44 **p** 1 i 1 i 1 i 1 i 1 45 redestrialis are generated at the sta 46 $^{47}_{48}$ of about 3.5m from the building. They move towards the end of the pathway, where the evacuation 48 49 tog to considered to finish 50 considered to mism.

⁵⁷ 3^3 These dimensions were selected in FloodPEDS tests to represent a typical real world urban built environment, i.e.
 59° composed by orthogonal urban fabric. More details are reported in (Bernardini et al., 2017b) 59 composed by orthogonal urban fabric. More details are reported in (Bernardini et al., 2017b).
60 final and influence due to the floodwater direction and so effects of nedestrian-nedestrian

 60 4 There is no influence due to the floodwater direction and so effects of pedestrian-pedestrian and pedestrians-
61 obstacles interactions can be better bighlighted 61 obstacles interactions can be better highlighted.
62

2.3. Generic simulator setup criteria

ee main objects compose the simulation environment of the setup-based generic simulator, besides

pedestrians⁵ (see Appendix A). The *floors* are the surfaces on which the pedestri 2.3. **Generic simulator setup criteria**
Three main objects compose the simulation environment of the setup-based generic simulator, besides
the pedestrians⁵ (see Appendix A). The *floors* are the surfaces on which the p 2.3. Generic simulator setup criteria
Three main objects compose the simulation environment of the setup-based generic simulator, besides
the pedestrians⁵ (see Appendix A). The *floors* are the surfaces on which the pede **2.3.** Generic simulator setup criteria
Three main objects compose the simulation environment of the setup-based generic simulator, besides
the pedestrians⁵ (see Appendix A). The *floors* are the surfaces on which the p **Generic simulator setup criteria**
bijects compose the simulation environment of the setup-based generic simulator, besides
ns⁵ (see Appendix A). The *floors* are the surfaces on which the pedestrians perform their
is th **2.3.** Generic simulator setup criteria
Three main objects compose the simulation environment of the setup-based generic simulator, besides
the pedestrians⁵ (see Appendix A). The *floors* are the surfaces on which the p **2.3. Generic simulator setup criteria**
Three main objects compose the simulation environment of the setup-based generic simulator, besides
the pedestrians⁵ (see Appendix A). The *floors* are the surfaces on which the **2.3. Ceneric simulator setup criteria**
Three main objects compose the simulation environment of the setup-based generic simulator, besides
the pedestrians⁵ (see Appendix A). The *floors* are the surfaces on which the 2.3. **Generic simulator setup criteria**

ee main objects compose the simulation environment of the setup-based generic simulator, besides

pedestrians² (see Appendix A). The *floors* are the surfaces on which the pedest nain objects compose the simulation environment of the setup-based generic simulator, besides
estrians⁵ (see Appendix A). The *floors* are the surfaces on which the pedestrians perform their
that is the street. The *por* bigets compose the simulation environment of the setup-based generic simulator, bestues
ans⁵ (see Appendix A). The *floors* are the surfaces on which the pedestrians perform their
at is the street. The *portals* represe The street. The *portals* represent both the entrances on which the pedestrians perform their
step street. The *portals* represent both the entrances into the simulation and the
stinations. The *servers* are useful to mod which the pedestrians perform their
ances into the simulation and the
and, more in general, to vehiculate
of such objects' properties and
resumed in Appendix B. In the
iscussed:
epresent the moment from building
r, becaus is the street. The *portals* represent both the entrances into the simulation and the stinations. The *servers* are useful to model queues and, more in general, to vehiculates' movements and behaviors. The combination of 3 Three main objects compose the si 4 5 the nedestrians⁵ (see Annendix A) $6\,$ \ldots percentains $\left(\sec r\right)$ percent $\left(r\right)$. 7 ⁸ motion, that is the street. The p_0 9 10 nedestrians' destinations. The served 11 podobitants dominators. The set θ 12 13 the pedestrians movements and 14 15 positioning defines 36 different setup possibilities, which are resumed in Appendix B. In the 16 Presente de mais de la propincia de la prop 17 ϵ 11 ϵ 1 ϵ 1 ϵ 1 18 Ionowing, each object configuration

- ²⁰ 1. *Entrance portals shape*. Two configurations are tested to represent the moment from building ²¹ 21 22 23 CAR by pedestrialis who try
- stinations. The *servers* are useful to model queues and, more in general, to vehiculates' movements and behaviors. The combination of such objects' properties and fines 36 different setup possibilities, which are resumed the state of the squared one, where entrance portals have a dimension of 3x1m and the scale object configuration and the related reasons are diseussed:
 tance portals shape. Two configurations are tested to represent th thes 36 different setup possibilities, which are resumed in Appendix B. In the object configuration and the related reasons are discussed:
 ee portals shape. Two configurations are tested to represent the moment from bu matical B. In the
theoretical behaviors:
d are adjacent to
the interaction
than 3.0m away
a and are placed
to replicate the
pathway (in the is object configuration and the related reasons are discussed:
 ee portals shape. Two configurations are tested to represent the moment from building

pedestrians who try to start the evacuation together, because of gro 2. *Servers* number, positioning, and properties. Servers are placed along the pathway is exerced at the exacuation together, because of group behaviors:

a. in the *rectangular* one, entrance *portals* have a dimension o 25 a. in the *rectangular* one, entrance *portals* have a dimension of $3x1m$ and are adjacent to 26 26 27 the wells The neds 28 and the wants. The pear 29 30 between them, starting the simulation closer to each other and lesser than 3.0m away 31 31 32
from the unmovable obstacle; 33 **From the state** case
- 34 35 b. in the *squared* one, 36 $\frac{37}{38}$ 1m away from the walls. The pedestrian density is about 1pp/m² to replicate the 38 39 40 Custom Simulator St
- to start the evacuation together, because of group behaviors:
ne, entrance *portals* have a dimension of $3x \ln a$ and are adjacent to
strian density is about $3p/m^2$ in order to increase the interaction
ing the simulation one, entrance *portals* have a dimension of $3x$ 1m and are adjacent to strian density is about $3pp/m^2$ in order to increase the interaction ing the simulation closer to each other and lesser than 3.0m away e obstacle;
whe the walls. The pedestrian density is about spp/m⁻ in order to increase the interaction
between them, starting the simulation closer to each other and lesser than 3.0m away
from the unmovable obstacle;
b. in the *squared* between them, starting the simulation closer to each other and lesser than 3.0m away
from the unmovable obstacle;
b. in the *squared* one, where entrance *portals* have a dimension of 3x3m and are placed
1m away from the from the unmovable obstacle;

b. in the *squared* one, where entrance *portals* have a dimension of 3x3m and are placed

1m away from the walls. The pedestrian density is about $1pp/m^2$ to replicate the

custom simulator s b. in the *squared* one, where entrance *portals* have a dimension of 3x3m and are placed

1m away from the walls. The pedestrian density is about $1pp/m^2$ to replicate the

custom simulator starting setup.
 Servers numbe 42 2. Servers number, positioning, and properties. Servers are placed along the pathway (in the 43 43 44 following "first convers") 45 following, that servers \int 46 47 following "second servers") to simulate the attraction of the pedestrians towards the buildings.
48 48 $\frac{49}{9}$ Considering the floor's len 50 Constability are *jobs* 5 fem 51 52 at the beginning of the floc 53 ⁵⁴ end of the *floor*, and finally 1 exit *portal*. The reference work distinguishes three main classes 55 (a) $\frac{1}{2}$ (b) $\frac{1}{2}$ (c) $\frac{1$ 56 57 **101 COLLUSTANCE LITER IN THE UNITED**

 61 ⁵ In MassMotion, *agents*. 62

Therefore, three "first servers" per side of the *floor* are tested. An alternative configuration of only two "first servers" is also studied to increase the interaction between the pedestrians. In both cases, only one "se Therefore, three "first servers" per side of the *floor* are tested. An alternative configuration of only two "first servers" is also studied to increase the interaction between the pedestrians. In both cases, only one "se Therefore, three "first servers" per side of the *floor* are tested. An alternative configuration of only two "first servers" is also studied to increase the interaction between the pedestrians. In both cases, only one "se Therefore, three "first servers" per side of the *floor* are tested. An alternative configuration of only two "first servers" is also studied to increase the interaction between the pedestrians. In both cases, only one "se Therefore, three "first servers" per side of the *floor* are tested. An alternative configuration of only two "first servers" is also studied to increase the interaction between the pedestrians. In both cases, only one "se Therefore, three "first servers" per side of the *floor* are tested. An alternative configuration of only two "first servers" is also studied to increase the interaction between the pedestrians. In both cases, only one "s Therefore, three "first servers" per side of the *floor* are tested. An alternative configuration of only two "first servers" is also studied to increase the interaction between the pedestrians. In both cases, only one "s Therefore, three "first servers" per side of the *floor* are tested. An alternative configuration of only two "first servers" is also studied to increase the interaction between the pedestrians. In both cases, only one "se Therefore, three "first servers" per side of the *floor* are tested. An alternative configuration of only two "first servers" is also studied to increase the interaction between the pedestrians. In both cases, only one "se Inerciore, times "inst servers" per side of the *floor* are tested. An alternative configuration of
only two "first servers" is also studied to increase the interaction between the pedestrians. In
both cases, only one "sec only two "first servers" is also studied to increase the interaction between the pedestrians. In
both cases, only one "second server" per side of the *floor* is tested in order to increase the
attraction by the unmovable o both cases, only one "second server" per side of the *floor* is tested in order to increase the attraction by the unmovable objects near the crossroads. These multiple setups are evaluated by placing servers in the middle attraction by the the movable objects near the crossroads. These multiple setups are evaluated
by placing servers in the middle (e.g. for the 0 to 1m class, 0.5m) or at the maximum value of
cach distance class (in the same by placing servers in the middle (e.g. for the 0 to 1m class, 0.5m) or at the maximum value of
each distance class (in the same example, 1m). Furthermore, the "first servers" position along
the pathway is tested according cach distance class (in the same example, 1m). Furthermore, the "first servers" position along
the pathway is tested according to three configurations, according to a parametric approach.
Tested positions are at *halfway*, the pathway is tested according to three configurations, according to a parametric approach.

Tested positions are at *halfway*, at *a quarter*, and at *an eighth* of the pathway. These

configurations allow investigating texted positions are at *halyway*, at *a quarter*, and at *an eignin* of the pathway. These
configurations allow investigating the impact of interferences between pedestrians at the
passage points (i.e. servers), hence if 1 2 only two "first servers" is also studied to increase the interaction between the pedestrians. In 3 $\frac{4}{1}$ hoth cases only and "see $\frac{4}{1}$ 5 both cases, only one seed $6\overline{6}$ 2 attraction by the unmovable objects near the crossroads. These multiple setups are evaluated 8 9 hypotherapy by property in the m 10 by placing servers in the m 11 12 each distance class (in the s 13 ¹⁴ the pathway is tested according to three configurations, according to a parametric approach. 15 and 1 16 17 **I** lested positions are at n_i 18 ¹⁹ configurations allow investigating the impact of interferences between pedestrians at the ²⁰ 20 contract con 21 \cdots \cdots \cdots \cdots 22 passage points (i.e. serve 23 24 obstacles exist. Finally, the probability that a pedestrian selects one of the "first servers" is 25 25 and 26 an 26 assumed according to two 27 assumed according to two 28 29 probability; by-literature, according to the real-world data about the frequency for each class 30 30 $\frac{31}{32}$ of distance from unmovable obstacles. 32 **Constant Community** Research

configurations allow investigating the impact of interferences between pedestrians at the
passage points (i.e. servers), hence if behavioral uncertainties towards the unmovable
obstacles exist. Finally, the probability tha passage points (i.e. servers), hence if behavioral uncertainties towards the unmovable
obstacles exist. Finally, the probability that a pedestrian selects one of the "first servers" is
assumed according to two configuratio bstacles exist. Finally, the probability that a pedestrian selects one of the "lirst servers" is
ssumed according to two configurations: *homogeneous*, if cach element has the same
robability; *by-literature*, according to 33 34 Figure I and Table I resume the to 35 ³⁶ by the entrance *portals* shape (R for rectangular; S for squared) and the "first servers" position along ³⁷ $37 \qquad \qquad 1 \qquad \qquad$ 38 a 1 d (0.0 ii 1.0 c 39 line patriway (8 for position 1/8 of 40 $\frac{41}{42}$ 1/2 of the path length), as shown in Figure 1. Furthermore, each group of setups is also characterized 42 43 hyperparameteristic approximation of 44 by the probability a pedestrial ex-45 *A*⁶ *servers'* number and position in respect to the wall, as resumed in Table 1.

Figure 1: Setup groups organized depending on the entrance portals' shape (columns) and the "first servers" position along the pathway (rows). The setup code is composed of four characters: the number and position of the servers in respect to the wall (A-B-C-D) as in Table 1, the probability a pedestrian can choose a server (H-L), the server position with respect to the start (2-4-8), and the shape of the entrance portal $(R-S)$.

Table 1: Setup code for the servers' position by considering their number and distance in respect of the side of the floor

(i.e., the buildings wall).

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2.4. Simulation outputs and comparison criteria

ulations are repeated 10 times due to the probabilistic rules in motion simulation (Ronchi et al.,

3b). 2.4. Simulation outputs and comparison criteria
Simulations are repeated 10 times due to the probabilistic rules in motion simulation (Ronchi et al.,
2013b).
The evacuation curve is expressed as the percentage of arrived p $\frac{5}{6}$ 2013b). 3 Simulations are repeated 10 times 4 $\frac{20150}{n}$

2.4. Simulation outputs and comparison criteria
Simulations are repeated 10 times due to the probabilistic rules in motion simulation (Ronchi et al.,
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The evacuation curve is expressed as the percentage of arrive **2.4.** Simulation outputs and comparison criteria
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2013b).
The evacuation curve is expressed as the percentage of arrive **2.4.** Simulation outputs and comparison criteria
Simulations are repeated 10 times due to the probabilistic rules in motion simulation (Ronehi et al.,
2013b).
The evacuation curve is expressed as the percentage of arrive **criteria**
motion simulation (Ronchi et al.,
edestrians [%] over the simulation
red for each tested condition.
le building during the evacuation
ve describing how the criteria for
along the path, depending on the
red accor **2.4.** Simulation outputs and comparison criteria
Simulations are repeated 10 times due to the probabilistic rules in motion simulation (Ronchi et al.,
2013b).
The evacuation curve is expressed as the percentage of arrive Eindeduce of the probabilistic rules in motion simulation (Ronchi et al., 2013b).

The evacuation curve is expressed as the percentage of arrived pedestrians [%] over the simulation

time [s]. The average evacuation curve Simulations are repeated 10 times due to the probabilistic rules in motion simulation (Koneni et al., 2013b).
The evacuation curve is expressed as the percentage of arrived pedestrians [%] over the simulation
time [s]. Th 2013b).
The evacuation curve is expressed as the percentage of arrived pedestrians [%] over the
time [s]. The average evacuation curve coming from the is considered for each tested con
The distance D_w [m] between each p The evacuation curve is expressed as the percentage of arrived pedestrians [%] over the simulation
time [s]. The average evacuation curve coming from the is considered for each tested condition.
The distance D_w [m] betw time [s]. The average evacuation curve coming from the is considered for each tested condition.
The distance D_w [m] between each pedestrian and the side of the building during the evacuation
process is tracked over the ts tracked over the pathway length, thus torming a curve describing now the criteria for
the obstacles attraction affect the pedestrians' trajectory along the path, depending on the
tup. To claborate this curve, D_w tren first derivative (for *SC* next to 1, the shapes of the curves and agree ouring to a quartile-based is, by grouping data over 3m-long pathway steps, according to the distance threshold for ∞ phenomena in motion consid the Euclidean Relative Difference between two vectors (for *ERD* next to 0, the curves can
be considered by FlooPEDS and based on previous works relating to the
akoba et al., 2005).
ing to previous works (D'Orazio et al., 8 1he evacuation curve is expressed 9 $_{11}^{10}$ time [s]. The average evacuation curve coming from the is considered for each tested condition. 11 12 \mathbb{E} $\$ 13 Ine distance D_w [m] between each 14 15 process is tracked over the pathway length, thus forming a curve describing how the criteria for 16 17 unmoverle existence etteration of 18 **uniformatic obstacts attraction at** 19 20 input setup. To elaborate this curve, D_w trend data are organized according to a quartile-based 21 21 22 analysis by grouping data over 23 analysis, by grouping data over 24 25 repulsive phenomena in motion co 26 $^{27}_{28}$ SFM (Lakoba et al., 2005). 28 2111 (2011

trends: 29 30 According to previous works (D 31 32 Performance Indicators (KPIs) are used for comparison purposes about evacuation curves and D_w
33 33 34 $35 \quad \text{$ **uchus.**

- ³⁷ the Secant Cosine *SC* [-], to measure the differences of shape between two curves, as their ³⁸ 38 39
 5 5 5 6 5 7 7 3 40 INSURGENTING THE LICE
- s, by grouping data over sin-iong painway steps, according to the distance threshold for

ephenomena in motion considered by FlooPEDS and based on previous works relating to the

akoba et al., 2005).

ing to previous work e pienoniena in motion considered by Proopeless and based on previous works related a
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ing to previous works (D'Orazio et al., 2015; Ronchi et al., 2013b), the follo
nance Indicators (KPIs) are used for ahood et al., 2005).

sing to previous works (D'Orazio et al., 2015; Ronchi et al., 2013b), the following Key

sing to previous works (D'Orazio et al., 2015; Ronchi et al., 2013b), the following Key

sing the Secant Cosin mg to previous works (*D* Orazot et al., 2013, Koncin et al., 20150), the ionowing key
anace Indicators (KPIs) are used for comparison purposes about evacuation curves, as their
the Secant Cosine SC [-], to measure the di the Secant Cosine *SC* [-], to measure the differences of shape between two curves, as their first derivative (for *SC* next to 1, the shapes of the curves can be considered similar);
the Euclidean Relative Difference *ER* the Secant Cosine *SC* [-], to measure the differences of shape between two curves, as their first derivative (for *SC* next to 1, the shapes of the curves can be considered similar);
the Euclidean Relative Difference *ER* for the secal cosine of [-], to measure the dimerences of shape between two curves, as then
first derivative (for SC next to 1, the shapes of the curves can be considered similar);
the Euclidean Relative Difference *ERD* [⁴² • the Euclidean Relative Difference *ERD* [-], to measure the overall agreement between two ⁴³ 43 44 europe of the new of the 45 curves, as the horm of the 46 47 be considered close);
48
- 49 the Euclidean Projection C 50 The Euchdean Projection C 51 52 possible fit between two curves (for EPC next to 1 the curves can be considered similar);
53
- 54 **c** the Difference between the 55 and Directories between the 56 57 underestimating/overestim 58 for the generic simulator are over those of the custom one). ϵ ⁰

Results are discussed through KPIs mean and standard deviation values for each of the 6 setup groups
identified in Figure 1, while extended results for all the 36 setups are reported in Supplementary
Materials S2. Results are discussed through KPIs mean and standard deviation values for each of the 6 setup groups
identified in Figure 1, while extended results for all the 36 setups are reported in Supplementary
Materials S2.
In addi Results are discussed through KPIs mean and standard deviation values for each
identified in Figure 1, while extended results for all the 36 setups are repor
Materials S2.
In addition, D_w results from generic and custom 1 $\frac{2}{3}$ identified in Figure 1, while extended results for all the 36 setups are reported in Supplementary 3 $\frac{4}{100}$ Motorials S2 5 Materials 52.

Results are discussed through KPIs mean and standard deviation values for each of the 6 setup groups
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In addition, D_w results from generic and custom simulators are compared between them and w
experimental percentage distributions by considering the three literature-based main
(Bernardini et al., 2017b): l in addition, D_w results from generic and custom simulators are compared between them and with the
experimental percentage distributions by considering the three literature-based main classes
(Bernardini et al., 2017b): experimental percentage distributions by considering the three interature-based main classes
(Bernardini et al., 2017b): lower than 1m; from 1m to 2m; higher than 2m. Percentages differences
due to the modelling logics at (Bernardmi et al., 2017b): lower than 1m; from 1m to 2m; higher than 2m. Percentages differences
due to the modelling logics at both microscopic and macroscopic levels are assessed to be compared
with acceptability thresh 7 In addition, D_w results from generic and custom simulators are compared between them and with the $\frac{8}{3}$ 8 9
experimental percentage distribu-10 experimental percentage district 11 12 (Bernardini et al., $2017b$): lower t 13 $\frac{14}{15}$ due to the modelling logics at both microscopic and macroscopic levels are assessed to be compared 15 $\qquad \qquad$ \qquad \q 16 11 11:1 11:1 11 17 With acceptability thresholds conc 18 19 al., 2009; Schadschneider et al., 2009; Shiwakoti et al., 2008). In particular, in case of D_w 20 21 \ldots according tion in white on he can 22 overestimation, results can be con-23 24 motion in critical floodwater conditions are not underestimated (i.e. flow effects in the central part of 25 25 and 26 an 26 an open shappel (Chow 1050)) 27 an open enanner (Cnow, 1999).

stationary at a server) is introduced to evaluate the impact of possible phenomena simulation, when the impact of evaluate the impact of evaluation, results can be considered as conservatively acceptable because risks for with acceptability intesholds concerning real-world data, which are up to about 10%-20% (Kobin et al., 2009). Schadschneider et al., 2009; Shiwakoti et al., 2008). In particular, in ease of D_w overestimation, results ca overestimation, results can be considered as conservatively acceptable because risks for pedestrians
motion in critical floodwater conditions are not underestimated (i.e. flow effects in the central part of
an open channe motion in critical Hoodwater conditions are not underestimated (i.e. How effects in the central part of
an open channel (Chow, 1959)).

Finally, pedestrians' evacuation timing analyses are performed. The maximum evacuatio an open channet (Chow, 1959)).

Finally, pedestrians' evacuation timing analyses are performed. The maximum evacuation time t_{max}

[s] is calculated to describe the overall time during which the pedestrians remain in the Finally, pecestrians evacuation timing analyses are performed. The maximum evacuation time t_{max} [s] is calculated to describe the overall time during which the pedestrians remain in the outdoor BE.
Similarly, the maximu [8] is calculated to describe the overall time during which the pedestrians remain in the outdoor BE.

Similarly, the maximum waiting time t_w [8] (i.e., that is the time in which a pedestrian remains

stationary at a *s* Similarly, the maximum waiting time t_w [s] (i.e., that is the time in which a peacstrian remains
stationary at a server) is introduced to evaluate the impact of possible queuing phenomena simulated
by the generic simula stationary at a *server*) is introduced to evaluate the impact of possible queuing phenomena simulated
by the generic simulator at the *servers*. It has been normalized by the maximum evacuation time t_{max}
to identify th by the generic simulator at the *servers*. It has been normalized by the maximum evacuation time t_{max} , to identify the waiting time precentage $W[\%]$ over the entire simulation. W considers how the effect of group dynam 29 Finally, pedestrians' evacuation ti 30 31 [s] is calculated to describe the ov 32 $\left[\text{g}\right]$ is calculated to describe the g . 33 34 Similarly, the maximum waiting 35 36 stationary at a *server*) is introduced to evaluate the impact of possible queuing phenomena simulated $\frac{37}{27}$ 37 38 39 by the generic simulator at the *serv* 40 ⁴¹ to identify the waiting time percentage $W[\%]$ over the entire simulation. W considers how the effect ⁴² 42 $\frac{43}{2}$ of organ dynamics can force no 44 or group dynamics can force per 45 ⁴⁶ simulator logics in respect of the i 47 48 the buildings but could represent. 49 and suitainly but could represent 50 51 calculated to estimate the speedine 52 53 are measured to reduce the impact of outliers as a consequence of particular simulation aspects in 54 55 (B 1 1 201 56 crowd motion (Ronchi et al., 201. 57 58 positions less or more favorable, neighbors behaviors, deadlocks phenomena, etc. Quartile-based 59 60 61 analyses of t_{max} , T , and W are performed and θ

portals shape to describe general uncertainties for the whole set of considered input setups. Only t_{max}
and F are compared to FloodPEDS outcomes since the custom simulator does not consider deadlocks
in the building a portals shape to describe general uncertainties for the whole set of considered input setups. Only t_{max} and F are compared to FloodPEDS outcomes since the custom simulator does not consider deadlocks in the building a portals shape to describe general uncertainties for the whole set of considered input setups. Only t_{max} and F are compared to FloodPEDS outcomes since the custom simulator does not consider deadlocks in the building a portals shape to describe general uncertainties for the whole set of considered input setups. Only t_{max} and F are compared to FloodPEDS outcomes since the custom simulator does not consider deadlocks in the building a **poortals** shape to describe general uncertainties for the whole set of consi-

and *F* are compared to FloodPEDS outcomes since the custom simulator

in the building attraction, while *W* outcomes are discussed independen *uals shape to describe general uncertainties for the whole set of considered input setups. Only* t_{max} *F are compared to FloodPEDS outcomes since the custom simulator does not consider deadlocks
he building attraction, wh* **Example 2** shows the evacuation curves for the whole set of considered input setups. Only *t_{max}*

and *F* arc compared to FloodPEDS outcomes since the custom simulator does not consider deadlocks

in the building attrac **EXECUTE 2** along to describe general uncertainties for the whole set of considered input setups. Only t_{max}

and F are compared to FloodPEDS outcomes since the custom simulator does not consider deadlocks

in the buildi cortals shape to describe general uncertainties for the whole set of considered input setups. Only t_{max}
and F arc compared to FloodPEDS outcomes since the custom simulator does not consider deadlocks
in the building att and *F* arc compared to FloodPEDS outcomes since the custom simulator does not consider deadlocks
in the building attraction, while *W* outcomes are discussed independently to evaluate the impact of
the queuing phenomena Solution in the building attraction, while *W* outcomes since the custom simulator does not consider deadlocks

in the building attraction, while *W* outcomes are discussed independently to evaluate the impact of

the queu 1 $\frac{2}{3}$ and F are compared to FloodPEDS outcomes since the custom simulator does not consider deadlocks $\frac{3}{2}$ $\frac{4}{4}$ in the building etteration while \overline{u} $5 \t{m}$ in the building attraction, while *m* $6\overline{6}$ $\frac{7}{8}$ the queuing phenomena on the evacuation timing in the generic simulator. 8

$\frac{12}{13}$ 3. Results 13

15 a \blacksquare \blacksquare 16 **J.I. EVACUALION CU**

EXECUTE: The building attraction, while *W* outcomes are discussed independently to evaluate the impact of the queuing phenomena on the evacuation timing in the generic simulator.
 3. Results
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3. Evacuation curves comparison
Eigure 2 shows the evacuation curves for the generic and custom simulators by considering the same
entrance *portals* 18 F 21 J 19 Figure \angle shows the evacuation cur entrance portals configuration, i.e., setup groups 1 to 3 are *rectangular*, 4 to 6 are *squared*, according
²¹ to Figure 1. Table 2, KN to Figure 1. Table 2: KPIs measuring differences between evacuation curves obtained from each setup tested on the generic simulator and the one obtained from the custom simulator. Results are shown in terms of mean and standard 23 generic simulator and the one obtained 24 deviation values according to the group of

25 resumes their comparisons, in respect of the custom simulator results, according to the selected KPIs, 26

 27 according to the same setup condit 28

3. Results
 3.1. Evacuation curves comparison

Figure 2 shows the evacuation curves for the generic and custom simulators by considering the same

entrance *portals* configuration, i.e., setup groups 1 to 3 are *rec* **3. Results**
 S1. Evacuation curves comparison

Figure 2 shows the evacuation curves for the generic and custom simulators by considering the same

nentrance *portals* configuration, i.e., setup groups 1 to 3 are *recta* **3.1. Evacuation curves comparison**

Figure 2 shows the evacuation curves for the generic and custom simulators by considering the same

entrance *portals* configuration, i.e., sclup groups 1 to 3 are *rectangular*, 4 t **3.1. Evacuation curves comparison**
Figure 2 shows the evacuation curves for the generic and custom simulators by considering the same
entrance *portals* configuration, i.e., setup groups 1 to 3 are *rectangular*, 4 to Figure 2 shows the evacuation curves for the generic and custom simulators by considering the same
entrance *portals* configuration, i.e., setup groups 1 to 3 are *rectangular*, 4 to 6 are *squared*, according
teriant con entrance *portals* confugnation, i.e., secting groups 11 to 3 are rectingular, 4 to 6 are *squared*, according
to Figure 1. Table 2: KPIs measuring differences between evacuation curves obtained from each setup tested on generis simulator and the one obtained from the custom simulator. Results are shown in terms of mean and standard
deviation values according to the geoping criteria shown in Figure 1.
resulting to the selected KPIs,
record resumes their compansons, in respect of the custom simulator results, according to the selected
according to the same setup conditions grouping. Average results per group are provided.
The results highlight that, when the according to the same setup conditions grouping. A verage results per group are provided.
The results highlight that, when the "first servers" position is closer to the entrance *portals*, that is for setup groups R3 and S The results highlight that, when the "irrst servers" position is closer to the entrance *portals*, that is for setup groups R3 and S3, the generic simulator outputs seem to be more similar to those of the custom simulator scup groups K3 and S3, the genere simulator outputs seem to be more simulat to those of the eustom
simulator. In fact, in these cases, *SC* increases and *ERD* decreases. As expected, *EPC* seems non to
be affected by the simulator. In fact, in these cases, SC increases and ERI decreases. As expected, EFC seems non to be affected by the setup, as it tends to 1 in all the cases. In general, the generic simulator seems to underestimate th 29 30 **Ine results highlight that, when the** 31 ³² setup groups R3 and S3, the generic simulator outputs seem to be more similar to those of the custom ³³ $33 \qquad 101$ 34 \ldots \ldots 35 SHIRTARDI. III TACI, III LIIESE CASES, μ 36 37 be affected by the setup, as it tends to 1 in all the cases. In general, the generic simulator seems to 38 38 39 and accrimentation of the second second ition 40 and resultate the safety condition 41 42 instance, Figure 2). Anyway, the *i* 43 44 setup meaning that the generic sin 45 **Example 200 Formation** 200 Finance 200 46 (a) \sim 46 (a) 47 as values range from 1 to 24%.

be affected by the setup, as it tends to 1 m all the cases. In general, the generic simulator seems to underestimate the safety conditions considering the first arrived pedestrian by about 30% (see, for instance, Figure 2) $^{49}_{50}$ Considering the specificities of the setup groups, R2, R3, and S3 are the only ones with $SC > 0.8$ and 50 51 $\sqrt{224}$ $\sqrt{24}$ $\sqrt{24}$ 52 ERD \verturnal equation in the state 53 characterized by smaller distances between the entrance *portals* and the *servers*. Slight differences 55 56
56 an ha noticed considering the my 57 Can be noticed considering the nu 58 59 pathway, as the standard deviation values of all the KPIs point out, ranging between 0.01-0.03. On 60

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 $6\overline{6}$ 7

61 62 63 64

the other hand, assigning the probability that a pedestrian selects one of the "first server" by-literature,
seems to move towards better *SC*, *ERD*, and *DAUC* values, thus increasing the shape similarity (see
extended r the other hand, assigning the probability that a pedestrian selects one of the "first server" by-literature, seems to move towards better *SC, ERD,* and *DAUC* values, thus increasing the shape similarity (see extended res the other hand, assigning the probability that a pedestrian selects one of the "first server" by-literature,
seems to move towards better *SC*, *ERD*, and *DAUC* values, thus increasing the shape similarity (see
extended r 1 ² seems to move towards better *SC*, *ERD*, and *DAUC* values, thus increasing the shape similarity (see 3 $\frac{4}{3}$ extended require for each setup in $\frac{4}{3}$ 5 calculated results for each setup in

 $\frac{1}{46}$ 47 Tuble 2. KI is measuring algerences bett

48 . *1.* 1.1 . 1. 1. 1. 1. 49 Simulator and the one obtained from the d 50 and the set of the
The set of the set of 51 values accoraing to the grouping criteria

22 Figure 2: Custom simulator evacuation curve (black dashed lined) compared to those of the generic simulator grouped *Particularly 12* 24 according to the criteria shown in Figure 1(straight lines).0-90s are omitted as no pedestrians complete the evacuation

$\frac{32}{22}$ 22 α α α **3.2. Comparison r**

Table 3 resumes the analysis of the D_w trend according to the RPIs and considering the median distribution on a 3m resolution along the pathway. Results are grouped according to the criteria shown in Figure 1 (straight distribution on a 3m resolution curve (black dashed lined) compared to those of the generic simulator grouped
 $\frac{1}{\sqrt{2}}$ and $\frac{1}{\sqrt{2}}$ and $\frac{1}{\sqrt{2}}$ and $\frac{1}{\sqrt{2}}$ and $\frac{1}{\sqrt{2}}$ and $\frac{1}{\sqrt{2}}$ and $\frac{1}{\sqrt$ While data for the 1st and 3rd guartie are available in Supplementary Materials S2. Average and

Singure 2: Custom simulator evacuation curve (black dashed lined) compared to those of the generic simulator granned

in Figure 2: Custom simulator evacuation curve (black dashed lined) compared to those of the generic simulator grouped
according to the criteria shown in Figure 1 (straight lines).0-90s are omitted as no pedestrians complete *according to the criteria shown in Figure 1 (straight lines).0-90s are omitted as no pedestrians complete the evacuation
in this timespan.*
3.2. Comparison between D_w **trend along the pathway**
Table 3 resumes the analy **I able 3 resumes the analysis of** $\frac{38}{39}$ distribution on a 3m resolution along the pathway. Results are grouped according to Figure 1 criteria, $1 \cdot 1 + C$ $41 \cdot 15$ $1 \cdot 20$ 41 while data for the 1 and 3 qua 43 standard deviation values per group are provided.

3.2. **Comparison between** D_w **trend along the pathway**
Table 3 resumes the analysis of the D_w trend according to the KPIs and considering the median
distribution on a 3m resolution along the pathway. Results are grouped **3.2. Comparison between** D_w **trend along the pathway**
Table 3 resumes the analysis of the D_w trend according to the KPIs and considering the median distribution on a 3m resolution along the pathway. Results are group **3.2. Comparison between** D_w **trend along the pathway**
Table 3 resumes the analysis of the D_w trend according to the KPIs and considering the median
distribution on a 3m resolution along the pathway. Results are group Table 3 resumes the analysis of the D_w trend according to the KPIs and considering the median distribution on a 3m resolution along the pathway. Results are grouped according to Figure 1 criteria, while data for the $1<$ Fable 3 resumes the analysis of the D_w trend according to the KPIs and considering the median
distribution on a 3m resolution along the pathway. Results are grouped according to Figure 1 criteria,
while data for the 1^s distribution on a 3m resolution along the pathway. Kesults are grouped according to Figure 1 enteria,
while data for the 1³⁴ and 3rd quartile are available in Supplementary Materials S2. Average and
standard deviation As for Section 2.1 results setup. As for Section 3.1 results, setup *portals* and the *servers* seem to le shown by the median D trends i Shown by the median E_W dends 1 53 groups R3, S2, and S3 ranging bet 55 setup groups, thus implying that the *server* constraint should be placed closer to the start to effectively 1 σ 1 \prime 1 σ 58 auract pedestrians near the unmo- sense, such results seem to confirm those on the evacuation curve. However, the SC variability

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between the setups in the groups demonstrates some differences in D_w trends, as standard deviation
values range from 0.07 to 0.12, while they are up to 0.20 considering the overall sample. Nevertheless,
it is worth noti between the setups in the groups demonstrates some differences in D_w trends, as standard deviation values range from 0.07 to 0.12, while they are up to 0.20 considering the overall sample. Nevertheless, it is worth noti between the setups in the groups demonstrates some differences in D_w trends, as standard deviation values range from 0.07 to 0.12, while they are up to 0.20 considering the overall sample. Nevertheless, it is worth noti between the setups in the groups demonstrates some differences in D_w trends, as standard deviation
values range from 0.07 to 0.12, while they are up to 0.20 considering the overall sample. Nevertheless,
it is worth noti Setup in the groups demonstrates some differences in D_w trends, as standard deviation

from 0.07 to 0.12, while they are up to 0.20 considering the overall sample. Nevertheless,

noticing that a limited correspondence b 1 ² values range from 0.07 to 0.12, while they are up to 0.20 considering the overall sample. Nevertheless, 3 $\frac{4}{1}$ it is worth noticing that a limited $5 \t{ii}$ is worth noticing that a minimum $6\overline{6}$ outputs on D_w appears according to the other KPIs, as shown by Table 3 samples.
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50 Lable 3: KPIs measuring alfferences bety 51 52 *simulator and the one obtained from the* 53 54 standard deviation values according to the 55 **55 and 200** and 200 and 20 56 Supplementary Materials S3.

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24 *first servers*" along the pathway. 19
Figure 3: Custom simulator Ind. quantile 20 rue de la casione simulator quae quae contra de la α arouned according to the evitoria shown 22 Soupen according to the criteria shown 24 Just servers along the painway.

³⁰ **3.3. Quartile analy**

 Figure 4: Comparison between the maxi 25 Repairs 1. Comparison between the main 26
gimulator distinguishing overall (blue be 27 Sandward alsunguishing overall four or 28
follows: "Setup name (Group name)" E 29 John Schip name (Group name) . Ex

The two simulators (1s difference between the procedure of the custom simulator (red cross) and the generic simulator (contention between the maximum evacuation time t_{max} of the custom simulator (red cross) and the gene The distinction between the maximum evacuation time t_{max} of the custom simulator (red cross) and the generic simulator distinguishing overall (blue box) and groups data (orange and green baxes). Outlier setups are marke **considering** all the setup tested but the outliers (blue box) and groups 'R' (i.e., rectangular process) and the generic simulator distinguishing overall (blue box) and groups data (orange and green boxes). Outlier setup 115

Figure 4: Comparison between the maximum evacuation time t_{max} of the custom simulator (red cross) and the generic

simulator distinguishing overall (blue box) and groups data (orange and green boxes). Outler set *Figure 4: Comparison between the maximum evacuation time* t_{max} of the custom simulator (red cross) and the generic simulator distinguishing overall (blue box) and groups data (orange and green boxes). Outler setups *Figure 4: Comparison between the maximum evacuation time* t_{max} of the custom simulator (red cross) and the generic simulator distinguishing overall (blue box) and groups data (orange and green boxes). Outlier setups *Shimmator assinguishing overalt (one box) and groups data (orange and green boxes).* On
Gollows: "Setup name (Group name)". Extended results for each setup are in Supplementary
Overall outcomes about the maximum evacua as annot *ione boo, that groups data toringe and green boxes). Datter setups are marked as* ame (*Group name*)". *Extended results for each setup are in Supplementary Materials S4.*

Alters about the maximum evacuation ti Overall outcomes about the maximum evacuation time t_{max} (Figure 4) show similar results between
the two simulators (1s difference between the custom simulator and the generic one mean value).
Concerning the distinction Overall outcomes about the maximum evacuation time t_{max} (Figure 4) show s
the two simulators (1s difference between the custom simulator and the gen
Concerning the distinction by setup, the percentage differences range $\frac{31}{2}$ Overall outcomes shout the maximum **OVERT OUTCOMES ADOUT THE MANY** 34 the two simulators (1s difference Concerning the distinction by s 37 Conversion of the distribution of $\frac{1}{2}$ 39 considering all the setup tested 41 rectangular portals seem to be negligible (5%) , even if groups 'R' (i.e., rectangular *entrance portals*) σ 1 σ 43 (a) $\frac{1}{1}$ $\frac{1}{1}$ $\frac{1}{1}$ $\frac{1}{1}$ $\frac{1}{1}$ $\frac{1}{1}$ $\frac{1}{1}$ $\frac{1}{1}$ $\frac{1}{1}$ 44 register slightly higher t_{max} values $^{46}_{47}$ pedestrians in those entrance areas, and their effects are increased by the high-density conditions (chout 2 me/m²) in the next value. (about *3 pp/m)* in the rectangular trajectories are farther from the pathway sides while they are approaching the "first servers" (as shown 52 $\frac{53}{54}$ in Figure 3). m $\frac{1}{5}$ and $\frac{1}{5}$.

25 Figure 5: boxplot representation of the maximum waiting time percentage W, distinguishing overall (blue box) and groups 26 27 data (orange and green boxes. Outlier setups are marked as follows: "Setup name (Group name)".
28

9,0%

7,0%

6,0%

6,0%

6,0%

9,0%

^{9,0%}

^{9,0%}

^{9,0%}

^{9,0%}

² (igure 5: boxplot representation of the maximum vatiling time percentage *W*, distinguishing overall (blue box) and groups

Figure 5: boxplot repre Figure 5: boxplot representation of the maximum vatiting time percentage W, distinguishing overall (blue box) and groups
 $\frac{1}{3,0\%}$
 $\frac{1}{3,0\%}$
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 e CL2R (R1)
 a. 4,0%
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 between all the setups in Figure 5: boxplot representation of the maximum vatiing time percentage W, distinguishing overall (blue box) and groups
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 $\frac{1}{3,$ Figure 5: boxplot representation of the maximum vatiting time percentage W, distinguishing overall (blue box) and groups
data (orange and green boxes. Outlier setups are marked as follows: "Setup mane (Group name)".
In ge *Figure 5: boxplot representation of the maximum wating time percentage W, distinguishing overall (blue box) and groups data (orange and green boxes. Outlier setups are marked as follows: "Setup name (Group name)".*
In ge regare 3. boxplot representation of the maximum watting time percentage n, assungtuating overal forte box) and groups
data (orange and green boxes. Outlier senaps are marked as follows: "Setup name (Group name)".
In gener In general, a queue formation trend can be noticed because all pedestrians start at the same tin
place, and they are "forced" to pass by the *server*. Some pedestrians could be forced to st
evacuation for some time. Thus, 30 In general, a queue formation trend can be noticed because all pedestrians start at the same time and c $\frac{1}{1}$ 1 1 1 $\frac{1}{2}$ $\frac{1}{2}$ 33 place, and they are forced to p 35 evacuation for some time. Thus, regarding the maximum waiting time percentage W , the comparison 36 hotwoon all the setups in Figure 5. octwoch an the setups in Figure 38 40 the *entrance portals* and the *server* maximum and minimum values are 43 maximum and minimum various and 45 in the range between 5-15s, which 47 like social attachment, group phenomena 9 11 49 (D 1' 1 2010) to stop (Bernardini et al., 2019).

 Figure 6: Comparison between the evaluation 25 right of comparison octricen the evaluation 26
gimulator distinguishing overall (blue be 27 Sandward alsunguishing overall four or 28
follows: "Setup name (Group name)" E 29 John Schip name (Group name) . Ex

Than in the custom sherive the evacuation flow F values of the custom simulator (red cross) and of the generic
 $\frac{1}{25}$ 4,50
 $\frac{1}{3,00}$

Figure 6: Comparison between the evacuation flow F values of the custom simula 4,00

3,50
 BHBR (R3) e

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 BHBR (R3) e
 $\frac{1}{3,00}$
 BHBR (R3) e
 $\frac{1}{3,00}$

Figure 6: Comparison between the evacuation flow F values of the custom simulator (red creation distinguishing overall (blue box) servers. On the other hand, no significant differences are due to the setup of the generic simulator (Figure 6: Comparison benveen the evacuation flow F values of the custom simulator (red cross) and of the generic simulator distinguishing overall (blue box) and groups data (orange and green boxes). Outlier setups are ma valuation distinguishing overall (blue box) and groups data (orange and green boxes). Outlier setups are marked as
sus: "Setup name (Group name)". Extended results for each setup are in Supplementary Materials 55.
sully, F Follows: "Setup name (Group name)". Extended results for each setup are in Supplementary Materials S5.

Finally, Figure 6 shows how group phenomena seem to have a greater impact in the generic software

than in the custom Finally, Figure 6 shows how group phenomena seem to have a greater impact in the generic software
than in the custom simulator, as the evacuation flows F are 30% smaller considering the mean values
of the setup groups. than in the custom simulator, as the evacuation flows F are 30% smaller considering the mean values
of the setup groups. Such phenomena could be linked to the aforementioned "forced" passage by the
servers. On the other $\frac{31}{2}$ Einelly Eigure 6 shows how group a many, a gut σ shows now group 34 than in the custom simulator, as the $\frac{36}{100}$ of the setup groups. Such phenome **Crack Setap Strategie:** Such proteins 39 servers. On the other hand, no sig ⁴¹ (considering all the setups tested, the percentage differences are \leq 5%, excluding the outliers).

46 24 Companison $\ddot{}$ **3.4.** Comparison v

of the setup groups. Such phenomena could be linked to the aforementioned "forced
servers. On the other hand, no significant differences are due to the setup of the $\frac{1}{2}$
(considering all the setups tested, the percent $\frac{49}{100}$ The positioning of "ettrection" 50 The positioning of attraction of 52 phenomena towards unmovable obstacles (i.e., the *floor* edges). According to Section 2.3, 53 homogeneous or by-literature setu 55 nonogeneous of by meranine seta 57 pedestrian can choose one of the "

47 Table 4: Pedestrians frequency percentag 49 of the generic simulator, grouped accord 51 (Bernardini et al., 2017b) and the custom 53 Materials S6.
54

56 Table 4 compares the D_w percenta obstacles from the generic simulat 59 COMMONS HOME THE SOMMER 61 data are considered as a reference

simulator. Results show non-significant differences between the setup groups, as the standard deviations range, in general, between 1-5%. On the other hand, the comparison with the custom simulator and the literature data simulator. Results show non-significant differences between the setup groups, as the standard deviations range, in general, between 1-5%. On the other hand, the comparison with the custom simulator and the literature data simulator. Results show non-significant differences between the setup groups, as the standard deviations range, in general, between 1-5%. On the other hand, the comparison with the custom simulator and the literature data simulator. Results show non-significant differences between the setup groups, as the standard deviations range, in general, between 1-5%. On the other hand, the comparison with the custom simulator and the literature data simulator. Results show non-significant differences between the setup groups, as the standard deviations range, in general, between 1-5%. On the other hand, the comparison with the custom simulator and the literature data simulator. Results show non-significant differences between the setup groups, as the standard deviations range, in general, between 1-5%. On the other hand, the comparison with the custom simulator and the literature data simulator. Results show non-significant differences between the setup groups, as the standard
deviations range, in general, between 1-5%. On the other hand, the comparison with the custom
simulator and the literature data simulator. Results show non-significant differences between the setup groups, as the standard
deviations range, in general, between 1-5%. On the other hand, the comparison with the custom
simulator and the literature data simulator. Results show non-significant differences between the setup groups, as the standard deviations range, in general, between 1-5%. On the other hand, the comparison with the custom simulator and the literature data simulator. Results show non-significant differences between the setup groups, as the divisions range, in general, between 1-5%. On the other hand, the comparison with simulator and the literature data shows more significa $s \frac{1}{2}D_w \leq 2m$, these differences are essentially due to the repulsive forces between pedestrians is
same, which induce lower frequency in this class of distance (negative differences). On the othe
d, for $D_w > 2m$, th the same, which induce lower frequency in this class of distance (negative differences). On the other
hand, for $D_0 \ge 2m$, the distances are higher than the ones from real-world and eustom simulator data
(positive differ custom simulator, although differences in hydrodynamic point of view, the generic simulator scens to denotive differences). Thus, from a hydrodynamic point of view, the generic simulator scens to overestimate the risk con 1 $\frac{2}{3}$ deviations range, in general, between 1-5%. On the other hand, the comparison with the custom 3 $\frac{4}{4}$ cinemator and the literature data 5 $6\overline{6}$ class $1 < D_w \le 2m$, these differences are essentially due to the repulsive forces between pedestrians in 8 $\frac{9}{10}$ the same which induce lower freq 10 and same, which meade fower freq 11 (1915) <u>- 1916</u> - 1926 - 1927 - 1928 - 1929 - 1929 - 1929 - 1929 - 1929 - 1929 - 1929 - 1929 - 1929 - 1929 - 19 12 hand, for $D_w>2m$, the distances are 13 ¹⁴ (positive differences). Thus, from a hydrodynamic point of view, the generic simulator seems to $15 \t\t u \t\t 1$ 16 17 overestimate the risk condition due 18 walls. In fact, the streets seem to behave like open channels and the water speed at the edge decrease 20 20 21 $(O_{\text{max}} 1050)$ there is written in dec. 22 (Chow, 1959), thus possibly made

$rac{27}{28}$ 3.5. Best setup discussion

(positive differences). Thus, from a hydrodynamic point of view, the generic simulator seems to
overestimate the risk condition during the evacuation due to the possible proximity of pedestrians to
walls. In fact, the stre overestimate the risk condition during the evacuation due to the possible proximity of pedestrians to
walls. In fact, the streets seem to behave like open channels and the water speed at the edge decrease
(Chow, 1959), thu trajectories. BL8S setup is characterized by the following features that support at the edge decrease (Chow, 1959), thus possibly inducing pedestrians' speed increment.
 3.5. Best setup discussion

Between all the setups (Chow, 1959), thus possibly inducing pedestrians' speed increment.
 3.5. Best setup discussion

Between all the setups tested, the BL8S (group S3) is the one that produced the

custom simulator, although differences i 3.5. **Best setup discussion**
ween all the setups tested, the BL8S (group S3) is the one that produced the closest results to the
con simulator, although differences in the modelling logics between them exist. In particula **i. Best setup discussion**
n all the setups tested, the BL8S (group S3) is the one that produced the closest result
simulator, although differences in the modelling logics between them exist. In particul
n SFM-based, bu **ILENT THE EVALUATE EVALUATE SET THE EVALUATE SET AS SET AND THE PREFIRENT SIMULAT SPHARED THE PREFIRENT SIMULAT SPHARED AS A SHOT CONTINUES AND AND THE SAMPLET SAMPLET AND ARE alternated by the following features that sup** republic to the BL8S (group S3) is the one that produced the closest results to the simulator, although differences in the modelling logics between them exist. In particular, they SFM-based, but the generic one ignores th nall the setups tested, the BL8S (group 55) is the one that produced the closest results to the simulator, although differences in the modelling logics between them exist. In particular, they is SFM-based, but the generic 30 Between all the setups tested, the BL8S (group S3) is the one that produced the closest results to the 31 31 $\frac{32}{3}$ custom simulator although differe 33 Chemical Community, while the community 34 35 are both SFM-based, but the gener 36 $\frac{37}{38}$ one of the simulated forces and is just considered as an "external" constraint for pedestrians' 38 39 40 trajectories. BL8S setup is charact 41 $^{42}_{43}$ the custom simulator:

- for simulator, atthough differences in the modeling togies between them exist. In particular, they
both SFM-based, but the generic one ignores the attraction force toward unmovable obstacles as
of the simulated forces and the simulated forces and is just considered as an "external" constraint for pedestrians
ries. BL8S setup is characterized by the following features that support the similarities with
om simulator:
The condition of the *squ* 44 The condition of the squa 45 - The condition of the squa 46 47 density of about 1pp/m², is 48 49 repulsive force between ne 50 repairs force occurrent per 51 52 which is preserved along the 53 times higher, so that pedestrians spread out at the very beginning of the pathway;
55 55 σ $\frac{1}{1}$
- 56 57 - *I wo jirsi servers* are pos 58 59 This condition seems to allow increasing the attraction towards unmovable obstacles and the 60

interaction between the pedestrians. Considering the distance from the side of the pathway,
the "first servers" are placed in the middle of each class of distance (i.e., *servers* at 0.5m and
1.5m from the wall), with a *b* ide of the pathway,
servers at 0.5m and
strians to select one
in simulating higher interaction between the pedestrians. Considering the distance from the side of the pathway,
the "first servers" are placed in the middle of each class of distance (i.e., *servers* at 0.5m and
1.5m from the wall), with a *b* interaction between the pedestrians. Considering the distance from the side of the pathway,
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1.5m from the wall), with a *b* interaction between the pedestrians. Considering the distance from the side of the pathway,
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1.5m from the wall), with a *b* interaction between the pedestrians. Considering the distance from the side of the pathway,
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1.5m from the wall), with a *b* interaction between the pedestrians. Considering the distance from the side of the pathway,
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1.5m from the wall), with a *b* interaction between the pedestrians. Considering the distance from the side of the pathway,
the "first servers" are placed in the middle of each class of distance (i.e., *servers* at 0.5m and
1.5m from the wall), with a interaction between the pedestrians. Considering the distance from the side of the pathway,
the "first servers" are placed in the middle of each class of distance (i.e., *servers* at 0.5m and
1.5m from the wall), with a interaction between the peacstrians. Considering the distance from the side of the pathway,
the "first servers" are placed in the middle of each class of distance (i.e., servers at 0.5m and
1.5m from the wall), with a *by-* 1 ²₃ the "first servers" are placed in the middle of each class of distance (i.e., *servers* at 0.5m and $\overline{3}$ $\frac{4}{15}$ and $\frac{4}{15}$ from the yvell) with $\frac{4}{15}$ $\frac{1.5\text{m}}{2}$ is $\frac{1.5\text{m}}{2}$ in the matrix with $\frac{1}{2}$ $6\overline{6}$ ⁷ of them. This element of the setup seems to reduce the MassMotion trend in simulating higher 8 9
medestrian-unmovable obs 10 Percentan annovaoie cos 11 12 **Start of the pathway could** 13 14 especially with very large groups of pedestrians. 15 (a) 1 (b) $\frac{1}{2}$ (c) $\frac{1}{2}$ (c)

the "first servers" are placed in the middle of each class of distance (i.e., servers at 0.5m and
1.5m from the wall), with a *by-literature* probability distribution for pedestrians to select one
of them. This element of 1.5m from the wall), with a *by-literature* probability distinution for pedestrians to select one
of them. This element of the setup seems to reduce the MassMotion trend in simulating higher
pedestrian-unmovable obstacles or them. I has element of the setup seems to reduce the MassMotion trend in simulating nigner
pedestrian-unmovable obstacles distances. Anyway, having *servers* extremely close to the
start of the pathway could represent a pectestrian-inmovable obstactes distances. Anyway, having *servers* extremely elose to the
start of the pathway could represent a problem for what it concerns queue phenomena,
especially with very large groups of pedestria start of the pathway could represent a problem for what it concerns queue phenomena,
especially with very large groups of pedestrians.
Figure 7 shows the evacuation curves and the D_w trends obtained from the proposed se especially with very large groups of pedestrians.

Figure 7 shows the evacuation curves and the D_w trends obtained from the proposed setup (red solid

lines) and the custom simulator (black dashed lines). According to t Figure / shows the evacuation curves and the $D₆$ trends obtained from the proposed setup (red solid
lines) and the custom simulator (black dashed lines). According to the results on KPIs introduced in
Section 3.4, nnes) and the custom simulator (black dashed times). According to the results on KPIs introduced in
Section 3.4, the evacuation curves are similar in shape and size (SC-0.78, FPC-1.01), close to each
other (ERD-0.13), and Section 3.4, the evacuation curves are similar in shape and size (SC=0.78, EPC=1.01), close to each
other (ERD=0.13), and without significant differences in underestimating/overestimating
contingencies (DAUC=9%). Anyway, i ontingencies (DAUC=9%). Anyway, it is worthy of notice that the generic simulated contingencies (DAUC=9%). Anyway, it is worthy of notice that the generic simulate the evacuation process for the first arrived pedestrians, 16 17 Figure / shows the evacuation cur 18 ¹⁹ lines) and the custom simulator (black dashed lines). According to the results on KPIs introduced in ²⁰ $20 \thinspace$ \thinspace 21 $\qquad \qquad$ \qquad \qquad 22 Section 5.4, the evacuation curves 23 ²⁴ other (ERD=0.13), and without significant differences in underestimating/overestimating ²⁵ 25 and 26 an 26 contingencias $(DALIC-0\%)$ Arian 27 contingencies (DAOC 270). Any v 28 29 up the evacuation process for the first arrived pedestrians, which can be considered as free to move 30 30 $\frac{31}{10}$ in the environment and to nass by 32 m and characterized and to pulse by 33 34 custom simulator better points out 35 ³⁶ the first and the last arrived pedestrians. However, in view of the above, considering such risk 37 38 39 conditions in terms of the pedest 40 manage to move in the floodwater without experiencing in instability problems), the two simulators 42 42 43 44 Product comparable results conce 45 46 evacuation process.
47

Pigure /: Comparison between the evac 26 and 2012 and 2013 and 201 27 Simulator (red solid lines) and the custo *servers position along the pathway*. Th 31 from the arrival of the first pedestrian to

Figure 7: Computison between the evacuation curves and the D_® transposition of the generic simulator (black dushed lines). The green dashed line indicates the "first simulator (red solid lines) and the custom simulator **Example 2018**
 Example 2018
 Example 2019
 Example 2019 Example 19 $\frac{1}{8}$ is a solution of the submodular properties towards $\frac{1}{8}$ is a solution of the evacuation curves and the *D_{is}* trends obtained from the BLSS setup of the generic multicure *f* red solid lines) Figure 7: Comparison between the evacuation curves and the D_o trends obtained from the BL8S setup of the generic
simulator (red solid lines) and the custom simulator (black dashed lines). The green dashed line indicates Comparison between the evacuation curves and the D_n rends obtained from the BL8S setup of the generic
 r (red solid lines) and the custom simulator (black dashed lines). The green dashed line indicates the "first the probability distributions in the exist of the last one.
The heartinal of the first pedestrian to the exit of the last one.
On the other hand, from a microscopic point of view, differences emerge in pedestrians' trajec On the other hand, from a microscopic point of view, differences emerge in pedestrians' trajectories, as the $D₉$ outcomes point out. In particular, the generic simulator BL8S setup seems to overestimate the pedestr On the other hand, from a microscopic point of view, differences emerge in pedestrians' rajectories,
as the D_w outcomes point out. In particular, the generic simulator BL8S setup seems to overestimate
the pedestrians' r as the D_w outcomes point out. In particular, the generic simulator BLSS setup seems to overestiche pedestrians' risk if considering their trajectories, because the setup and the model force the travel along larger trajec 34 On the other hand, from a microsc 36 as the D_w outcomes point out. In particular, the generic simulator BL8S setup seems to overestimate 37 " ¹ 38 and the set of the 39 line pedestrians risk if considering travel along larger trajectories towards the evacuation target. This implies higher exposition for 44 Peucstrians to the Hoodwaters (Che ⁴⁶ server") as shown in Figure 7. Table 5 summarizes the KPIs values concerning the D_w trends ⁴⁷ ⁴⁸ comparison showing differences i 49 comparison, showing universities 51 the probability distributions in cl agreement with the real-world di 54 agreement with the rest were at 56 considered as preliminary acceptal $^{58}_{59}$ al., 2009; Shiwakoti et al., 2008).

 $\frac{1}{2}$ $\frac{1}{2}$ 10 Tuble 5. KI is measuring algerences bett

 and the context simulates (suggestionally such 12 and the custom simulator (quartile analys

24 Table 6: Pedestrians' frequency percenta *Lable 6. Leadsh and Jrequency percent* 26
hest setup (RI 85) with the literature distr 27 consemp (DDow) with the increased also 28
Pous utges differences between literature 29 Percentuge differences between therature

Euterature data 29

Custom simulator 23 (L: -6) 66 (L: +16) 11 (L: -10)

BL8S setup 39 (L: +16; C: +16) 37 (L: -13; C: -29) 25 (L: +4; C: +14)

Table 6: Pedestrians' frequency percentage distribution for each distance cla Custom simulator 23 (L: -6)

BLSS setup 39 (L: +10; C: +16) 37 (L: -13; C: -29) 25 (L: -14; C: +14)

Table 6: Pedestrians' frequency percentage distributions for each distance class: comparison of the generic simulator

b **BL8S setup** 39 (L: +10; C: +16) 37 (L: -13; C: -29) 25 (L: +4; C: +14)
Table 6: Peckstrians' frequency percentage distribution for each distance class: comparison of the generic simulator
best setup (BL8S) with the liter Table 6: Pedestrians' frequency percentage distribution for each distance class: compariso
best setup (BL8S) with the literature distributions (Bernardini et al., 2017b) and the custom
Percentage differences between liter contrained in the production in the production in the production in the maximum of the maximum of the maximum of the significant is almost identical between the two analyzed software, thus confirming on-particular underes Finally, Table 7 shows the pedestrians' evacuation timing data concerning: (a)
vacuation time t_{max} , which is almost identical between the two analyzed software, then-particular underestimating/overestimating safety cont pedestrians' evacuation timing data concerning: (a) the maximum

s almost identical between the two analyzed software, thus confirming

g/overestimating safety contingencies, (b) the waiting time percentage

ow F, whose v 35 Finally, Table / shows the pede evacuation time t_{max} which is alm 40 non-particular underestimating/over ⁴² *W*, and (c) the evacuation flow *F*, whose values are by the way in line with the generic simulator $\frac{43}{43}$ overall using.

14 $\frac{15}{16}$ 4. Conclusions 16

12 13

EVACUATE 127 (C: 2%; G: 1%)

10% (C: -; G: 2%)

4%)

Table 7: Comparison of the maximum ovacuation time t_{one}, the watting time percentage W, and the evacuation 27 (C: 2%) $\left\{\n \begin{aligned}\n 127 & (C: 2\% \text{ } G: 1\%)\n \end{aligned}\n \right.\n \left\{\n \begin{aligned}\n 127 & (C: 2\% \text{ } G: 1\%)\n \end{aligned}\n \right.\n \left\{\n \begin{aligned}\n 128 & (C: -; G: 2\%)\n \end{aligned}\n \right.\n \left\{\n \begin{aligned}\n 128 & (C: -; G: 2\%)\n \end{aligned}\n \right.\n \left\{\n \begin{aligned}\n 128 & (C: -; G: 2\%)\n \end$ Table 7: Comparison of the maximum ovacuation time t_{mus}, the waiting time percentage W , and the evacuation flow F of
the generic simulator best setup (BL8S): percentage differences between the custom simulator (C) and the generic sinulator best setup (BL8S): percentage differences between the custom simulator (C) and the generic
software median data (G) are pointed out into brackets.
 4. Conclusions
 19. Conclusions
 19. Conclusion software median data (G) are pointed out into brackets.
 4. Conclusions

The present work is a very first attempt to implement an outdoor flood evacuation model in a generic

evacuation simulation software (MassMotion) t **4. Conclusions**
The present work is a very first attempt to implement an outdoor flood evacuation model in a generic
evacuation simulation software (MassMotion) to ease and speed-up the risk assessment analyses by
using a **4. Conclusions**
The present work is a very first attempt to implement an outdoor flood evacuation model in a generic
evacuation simulation software (MassMotion) to ease and speed-up the risk assessment analyses by
using a ¹² Constraints of the system of the system of the system of the system and the system of the system of the system of evacuation simulation software (MassMotion) to case and speed-up the risk assessment analyses by using The present work is a very first attempt to implement an outdoor flood evacuation model in a generic
evacuation simulation software (MassMotion) to ease and speed-up the risk assessment analyses by
using a quick no-code mo evacuation simulation software (MassMotion) to case and specu-up the risk assessment analyses by
using a quick no-code modification approach. Functions and features already included in the generic
software are used to this using a quick no-code modification approach. Punctions and teatures already included in the genere
software are used to this end. Thus, different setups are tested to describe the pedestrians-floodwaters
interactions durin software are used to this end. Inus, different setups are tested to describe the pedestrians-floodwaters
interactions during a flood evacuation in a simple typological scenario like a straight and flat street.
As a benchma interactions during a flood evacuation in a simple typological secrario like a straight and flat street.
As a benchmark, a previously developed and tested custom flood evacuation simulator was selected,
that is FlooPEDs (F As a benemark, a previously developed and tested custom flood evacuation simulator was selected, that is FlooPEDs (Flooding Pedestrians' Evacuation Dynamics Simulator). Stationary flood conditions and compact groups of 10 that is FlooPEDs (Flooding Pedestrians' Evacuation Dynamics Simulator). Stationary flood
conditions and compact groups of 10 pedestrians are considered in the comparison, which is
consistent with basic outdoor BEs conditio conditions and compact groups of 10 pedestrians are considered in the comparison, which is
consistent with basic outdoor BEs conditions for evacuation after the event's peak, but sufficiently
detailed to represent a valid consistent with basic outdoor BEs conditions for evacuation after the event's peak, but sufficiently detailed to represent a valid preliminary test. Simulation outputs have been organized to identify the best setup, which ¹⁸ The present work is a very first attempt to implement an outdoor flood evacuation model in a generic ¹⁹ 19 20 21 Cyacuation simulation software (iv 22 and 22 an 23 using a quick no-code modification approach. Functions and features already included in the generic 24 24 25
software are used to this and Thus 26 soliward are used to this cha. Thus 27 28 interactions during a flood evacua 29 30 As a benchmark a previously deve 31 and α continuously a provide α 32 **1. PLACE COMPANY** 33 that is FloopEDs (Flooding Pe 34 $\frac{35}{36}$ conditions and compact groups of 10 pedestrians are considered in the comparison, which is 36 and 1 c 1 37 38 **CONSISTENT WILL DASIC OUTCOOL DES** 39 40 detailed to represent a valid preliminary test. Simulation outputs have been organized to identify the 41 41 $\frac{42}{42}$ host sotup which is the one that pr 43 best setup, which is the one that pr 44 45 Considering the best setup, the comparison of the results shows slight differences between the two 46 46 $\frac{47}{1000}$ software in simulating a flood evaluation 48 **Solimare** in Simalaling a nooa cra 49 50 simulation code. Indeed, from a 51 52 represent the main effects of the 53 54 55 liming (i.e., evacuation curves, flo

4%)

3.75 (C: -33%; G: -
4%)
and the evacuation flow F of
or (C) and the generic

differences with respect to the custom simulator still exist. In particular, the generic simulator seems
to overestimate the risk for pedestrians by computing higher distances from unmovable objects, which
also implies low differences with respect to the custom simulator still exist. In particular, the generic simulator seems
to overestimate the risk for pedestrians by computing higher distances from unmovable objects, which
also implies low differences with respect to the custom simulator still exist. In particular, the generic simulator seems
to overestimate the risk for pedestrians by computing higher distances from unmovable objects, which
also implies low 1 $\frac{2}{3}$ to overestimate the risk for pedestrians by computing higher distances from unmovable objects, which $\frac{3}{2}$ $\frac{4}{100}$ also implies lower execution and 5 also implies lower evacuation spec

differences with respect to the custom simulator still exist. In particular, the generic simulator seems
to overestimate the risk for pedestrians by computing higher distances from unmovable objects, which
also implies low differences with respect to the custom simulator still exist. In particular, the generic simulator seems
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also implies low differences with respect to the custom simulator still exist. In particular, the generic simulator seems
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to overestimate the risk for pedestrians by computing higher distances from unmovable objects, which
also implies low differences with respect to the custom simulator still exist. In particular, the generic simulator secons
to overestimate the risk for pedestrians by computing higher distances from unmovable objects, which
also implies lo differences with respect to the custom simulator still exist. In particular, the generic simulator seems
to overestimate the risk for pedestrians by computing higher distances from unmovable objects, which
also implies low differences with respect to the custom simulator still exist. In particular, the generic simulator secons
to overestimate the risk for pedestrians by computing higher distances from unmovable objects, which
also implies lo to overestimate the risk for pectestrians by computing higher distances from unmovable objects, which
also implies lower evacuation speed and higher exposure to the water flow for pedestrians.
The proposed setup developmen also mphics lower evacuation speed and ingner exposure to the water flow tor pedestrians.
The proposed setup development and comparison methodology could be also extended to other
existing generic simulation tools, especia The proposed setup development and comparison methodology could be also extended to other
existing generic simulation tools, especially those based on similar modelling logics, thus providing
preliminary tests in simple ou existing genere simulation toots, especially those based on similar modelling logies, thus providing
preliminary tests in simple outdoor BE conditions. From this point of view, although the current
simple setup of the gene preliminary tests in simple outdoor BF conditions. From this point of view, although the current
simple setup of the generic simulator seems to well represent the flood evacuation conditions, future
works should provide mo simple setup of the generic simulator seems to well represent the flood evacuation conditions, future
works should provide modifications to the evacuation simulation code to include SFM-related
interactions as proposed by works should provide modifications to the evacuation simulation code to include SFM-related interactions as proposed by the literature works. This action will ensure a more detailed description either of. (1) the outdoor e nteractions as proposed by the interature works. This action will ensure a more detailed description
either of. (1) the outdoor evacuation behaviors in complex BEs (i.e., with the effective
implementation of unmovable obje enther of. (1) the outdoor evacuation behaviors in complex Biss (i.e., with the effective implementation of unmovable objects like trees, walls, fences, that can have an attractive effect on the pedestrians); and (2) the f mplementation of unmovable objects like trees, walls, teness, that can have an attractive effect on
the pedestrians); and (2) the flood conditions, that is the variations in floodwaters levels to represent
hydrodynamics co $\frac{48}{49}$ quantities. nydrodynamics conditions which can vary over time and space, thus affecting the pedestrians' motion
and decision-making). The generic simulator software could also directly use data from external
hydrodynamic simulators to and decision-making). The generic simulator software could also directly use data from external
hydrodynamic simulators to represent the flood levels conditions variability over the simulation time,
and so to directly test nyaroayname simulators to represent the flood tevels conditions variability over the simulation time,
and so to directly test the effects on the pedestrians' motion. Additional tests on more refined
scenarios are still enc and so to directly test the citects on the pedestrians' motion. Additional tests on more refined
scenarios are still encouraged to verify behavioral evacuation aspects (for instance, by investigating
larger groups of pedes ⁷ The proposed setup development and comparison methodology could be also extended to other 8 9 evicting generic simulation tools 10 CADING SCHOTIC DIMENSION LODG, 11 12 preliminary tests in simple outdo 13 $\frac{14}{15}$ simple setup of the generic simulator seems to well represent the flood evacuation conditions, future $15 \t 1 \t 5$ 16 $\frac{1}{1}$ 11 $\frac{1}{1}$ 11 $\frac{1}{1}$ 11 $\frac{1}{1}$ 17 works should provide modificati 18 $\frac{19}{20}$ interactions as proposed by the literature works. This action will ensure a more detailed description 20 **11** . 21 $\mathcal{L}(1)$ $\mathcal{L}(1)$ $\mathcal{L}(2)$ $\mathcal{L}(2)$ $\mathcal{L}(3)$ $\mathcal{L}(4)$ $\mathcal{L}(2)$ $\mathcal{L}(3)$ $\mathcal{L}(4)$ 22 entremed only the outcool evaluation 23 24 implementation of unmovable objects like trees, walls, fences, that can have an attractive effect on 25 25 26 $\frac{26}{\sqrt{2}}$ the nedestriana): and (2) the flood 27 and pedestrians), and $\left(\frac{2}{\pi}\right)$ are noted 28 29 hydrodynamics conditions which can vary over time and space, thus affecting the pedestrians' motion 30 30 31 and decision-making). The gener 32 and decision making). The generic 33 34 hydrodynamic simulators to repres 35 $\frac{36}{37}$ and so to directly test the effects on the pedestrians' motion. Additional tests on more refined 37 38 (a) $\frac{1}{2}$ (b) $\frac{1}{2}$ (c) $\frac{1$ 39 scenarios are suit encouraged to v 40 ⁴¹ larger groups of pedestrians and/or with different physical and social features, or different 42 43 44 CHANDIMICHES SUCH as HOTC COMPI 45 46 model to better represent real emergency scenarios and to evaluate human motion evacuation 47 47 49 quantities.

scenarios are still encouraged to verify behavioral evacuation aspects (for instance, by investigating
larger groups of pedestrians and/or with different physical and social features, or different
environments such as more 50 51 Nevertheless, the performing resu 52 $\frac{53}{54}$ simulator could be able to simulate human behavior during flood evacuations in outdoor BEs. Thus, 54 **Experience** Press, Pre 55 56 such a steup-based generic simula 57 58 Authorities to preliminary assess evacuation risks in BEs, to propose risk-mitigation strategies (i.e. 59 60 61 alemeetutat taybut modification

pedestrians by also using wayfinding and alert systems, management actions by rescuers,

"invacuation" strategies) and finally to test their effectiveness by a user-centered and simulation-
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"invacuation" strategies) and finally to test their effectiveness by a us

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both indo pedestrians by also using wayfinding and alert systems, management actions by rescuers, "invacuation" strategies) and finally to test their effectiveness by a user-centered and simulation-
based approach. this kind of simu From the evacuess is safety in

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7.09.549 d approach. this kind of simulation tool could be hence used to increase the evacuees' safety in
indoor and outdoor BEs, characterized by similar scenario conditions (e.g. wide spaces in public
ings or undergrounds), in bo 1 $\frac{2}{3}$ "invacuation" strategies) and finally to test their effectiveness by a user-centered and simulation-3 $\frac{4}{100000}$ corresponds this kind of simulations 5 *based approach*. This Kind of simular $6\overline{6}$ both indoor and outdoor BEs, characterized by similar scenario conditions (e.g. wide spaces in public 8 8 $\frac{9}{9}$ buildings or undergrounds) in bot 10 candings of andergrounds), in our

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- indoor and outdoor BEs, characterized by similar scenario conditions (e.g. wide spaces in public
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39 6. Appendix A 40 **11**

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6. Appendix A
Figure 8 shows some main views of the *floor* configurati Soc. 61, 102253. https://doi.org/10.1016/j.ses.2020.102253
 6. Appendix A

Figure 8 shows some main views of the *floor* configuration simulating the linear pathway for the

verification tests. In particular, *portals* **6. Appendix A**
Figure 8 shows some main views of the *floor* configuration simulating the linear pathway for the
verification tests. In particular, *portals* and *servers* (MassMotion Guide, 2020) are introduced to
repro 42 Figure 8 shows some main views of the *floor* configuration simulating the linear pathway for the 43 44
regulation to the neutral on n 45 vermeation resist in particular, p_0 46 47 reproduce the attraction of the *agents* (i.e. pedestrians) towards unmovable obstacles (i.e. buildings).
48 48 49 We offered the specific software c 50 resolution of the specific software c 51 52 in square brackets, where needed.

 54 Futrance only and destination port 55 56 1 1 1 1 1 2 3 57 are placed close to the later *floor* 1 58 and buildings according to the considered experimental-based model (Bernardini et al., 2017b). An 60 60 component contract component contract contract contract contract contract contract contract contract contra

contract co

entrance only portal (whose dimensions depend on the setup tested) and a *destination portal* are placed at each *floor* side. Figure 8-B shows two views of the *entrance portal* position.
The *servers* are introduced to i 1 $\frac{2}{3}$ placed at each *floor* side. Figure 8-B shows two views of the *entrance portal* position. 3

entrance only portal (whose dimensions depend on the setup tested) and a *destination portal* are placed at each *floor* side. Figure 8-B shows two views of the *entrance portal* position.
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placed at each *floor* side. Figure 8-B shows two views of the *entrance portal* position.
The *servers* are introduced to i placed at each *jloor* side. Figure 8-B shows two views of the *entrance portal* position.
The *servers* are introduced to increase the attraction behavior towards unmovable obstacles, that are
the pathways sides. The star The *servers* are introduced to mercase the attraction behavior towards unmovable obstactes, that are the pathway sides. The start points of the *servers* (whose number depends on the setup tested) are placed at cach *flo* the pathways sides. The start points of the *servers* (whose number depends on the setup tested) are
placed at each *floor* lateral side, as shown by Figure 8-A. In respect to the pathway length, the *servers*
were tested placed at each *floor* lateral side, as shown by Figure 8-A. In respect to the pathway length, tivere tested in three different positions: halfway, a quarter, and an eighth of the *floor*. Thu part of the pathways is inten were tested in three different positions: halfway, a quarter, and an eignth of the *floor*. Thus, the first
part of the pathways is intended to replicate the pedestrians' organization alongside the pathway side,
being the part of the pathways is intended to replicate the pedestrians organization alongside the pathway side,
being the *agents* attracted by the *servers* start points (Bernardini et al., 2017b). Concerning these start
points' d being the *agents* attracted by the *servers* start points (Bernardmi et al., 2017b). Concerning these start points' distances from the *floor* lateral edge, multiple setups were also tested in order to represent the class $\frac{4}{100}$ The same are introduced to increase 5 The servers are introduced to firm $6\overline{6}$ the pathways sides. The start points of the *servers* (whose number depends on the setup tested) are $\frac{8}{3}$ 8 $\frac{9}{2}$ placed at each floor lateral side as 10 placed at each *from* faither side, as 11 12 were tested in three different posit 13 ¹⁴ part of the pathways is intended to replicate the pedestrians' organization alongside the pathway side, $15 \t1 \t1$ 16 17 being the *agents* attracted by the se 18 ¹⁹ points' distances from the *floor* lateral edge, multiple setups were also tested in order to represent the 20 21 ϵ 1. ϵ 22 Classes of distance by including (E 23 24 a single internal connection, the *dispatch*, to a single end point (placed near to the pathways end, at 25 25 and \sim 25 and \sim 25 and \sim 25 and 25 and 25 and 25 and 26 and 27 a 26 the destination portal $\mathbf{p}_{\mathbf{v}}$ this way 27 and acsumation portary. By this way 28 edge by reproducing the maximum attraction phenomena for building-pedestrians distances of about 30 30 $\frac{31}{2}$ 2m (Remardini et al. 2017b) 32 $\frac{200}{201}$ $\frac{32}{201}$

points' distances from the *Jioor* lateral edge, multiple setups were also tested in order to represent the classes of distance by literature (Bernardini et al., 2017b). Moreover, *servers* are connected through a single i classes of distance by literature (Bernardini et al., 2017b). Moreover, servers are connected through
a single internal connection, the *dispatch*, to a single end point (placed near to the pathways end, at
the *destinatio* a single internal connection, the *atspaten*, to a single end point (placed near to the patiways end, at the *destination portal*). By this way, the configuration tries to force the *agents* to move near the *floor* edge b the *aestination portat*). By this way, the configuration tries to forec the *agents* to move near the *jioor*
edge by reproducing the maximum attraction phenomena for building-pedestrians distances of about
2m (Bernardini the proportion of the maximum attraction phenomena for building-pedestrians distances of about (Bernardini et al., 2017b).
 agents' motion has been configurated so as to link them towards the *servers* placed on the same mardini et al., 2017b).
 ents' motion has been configurated so as to link them towards the *servers* placed on the same

ion *floor* side, and then towards the final *destination portal*. In particular, the *agents* are
 the state of the same of side, and then towards the final *destination portal*. In particular, the *agents* are it is the elements of the *server* according to two distri ion *Jioor* side, and then towards the final *destination portal*. In particular, the *agents* between the clements of the *server* according to two distributions: homogeneous, wave the same of probability in choosing the 33 34 I he *agents* motion has been conti 35 $\frac{36}{37}$ generation *floor* side, and then towards the final *destination portal*. In particular, the *agents* are 37 38 1:111. 1. 1. 1. C 39 **alvided between the elements of** 40 $^{41}_{42}$ agents have the same of probability in choosing the related *server*, and by-literature, according to the 42 43
mod would dote shout the freque 44 ICAI-WOTH data about the fieque 45 dispatches also increase the possibility of motion interaction between *agents* moving from the two 47 47 48 start points to the unique end point 49 Start points to the amplie one point

51 1. *agents* are initially generate 52 exits [approach: standard walk to target; Target: server exit]. Each server influences the 54 55 56 agents motion as a wayp 57 58 *server* length is not relevant);

- 2. no limitations in the exit flows are considered [*Processors: unlimited*; *Capacity: infinite*;
 Contact time: disabled]. The impact of queueing phenomena on the *server* motion steps and

at the exit can be reduced b no limitations in the exit flows are considered [*Processors: unlimited; Capacity: infinite;*
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Contact time: disabled]. The impact of queueing phenomena on the server motion steps and
at the exit can be reduced by combining 2 Contact time: disabled]. The impact of queueing phenomena on the server motion steps and $\frac{2}{3}$ $3 \left(\frac{1}{2} \right)$ $\frac{4}{100}$ of the evit can be reduced by $5 \t\t at the **crit** can be reduced to$
- 2. no limitations in the exit flows are considered [*Processors: unlimited; Capacity: infinite;*
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at the exit can be reduced by combining this s no limitations in the exit flows are considered [*Processors: unlimited; Capacity: infinite;*
 Contact time: disabled]. The impact of queueing phenomena on the *server* motion steps and

at the exit can be reduced by com along the examples are considered [*Processors: unlimited; Capacity: infinite;*
 Contact time: disabled]. The impact of queueing phenomena on the *server* motion steps and

at the exit can be reduced by combining this se $6\overline{6}$ 3. the correct evacuation direction is identified in a unique manner to avoid coming-and-going 8 9 hebaviors and street-cross **Collaboration** and street cross 12 evacuation conditions Dis along the evacuation motic

 $E_{i\alpha\mu\nu\alpha}$ ℓ_1 anouall flags configuration via 46 rigare 6. overall floor configuration vie 48 view (*b)* and some *of the servers include* 50 (*bine point)* and

Example 3: overall floor configuration view (*d*), by including the portals at the enablogitnting of the floor in plan and 3D view (*B*) and some of the servers included along the floor by including the access point (gr 55 Lach simulated *agent* moving on ⁵⁷ Rehaviour Tab setup interface Co **delay** [*Population: drrival -> inst*

current advances by literature on these aspects have been provided for the flood evacuation case. The *agents'* queue spacing has been similarly set up according to the default normal distribution (minimum=0m, maximum=1m, dvances by literature on these aspects have been provided for the flood evacuation case. The
queue spacing has been similarly set up according to the default normal distribution
m=0m, maximum=1m, mode=0.25m, standard devia current advances by literature on these aspects have been provided for the flood evacuation case. The *agents'* queue spacing has been similarly set up according to the default normal distribution (minimum=0m, maximum=1m, current advances by literature on these aspects have been provided for the flood evacuation case. The agents' queue spacing has been similarly set up according to the default normal distribution (minimum=0m, maximum=1m, mo current advances by literature on these aspects have been provided for the flood evacuation case. The *agents'* queue spacing has been similarly set up according to the default normal distribution (minimum=0m, maximum=1m, current advances by literature on these aspects have been provided for the flood evacuation case. The *agents'* queue spacing has been similarly set up according to the default normal distribution (minimum=0m, maximum=1m, eurrent advances by literature on these aspects have been provided for the flood evacuation case. The *agents'* queue spacing has been similarly set up according to the default normal distribution (minimum-0m, maximum-1m, to each *agent* [assigned goal -> grouped: lowest cost] by hence representing an improbehavior towards the *floor* limits where they are generated.
 7. Appendix B

Setup symbol and property 1 $\frac{2}{3}$ agents' queue spacing has been similarly set up according to the default normal distribution 3 $\frac{4}{100}$ (minimum - 0m movimum - 1m m 5 (11111111111111-0111, 1114X111111111-1111, 111 $6\overline{6}$ ⁷ selected *direction bias* is "none" 8 9 configuration of nortals and same 10 comparation of *portals* and serve 11 12 to each *agent* [*assigned goal* \rightarrow *gl* 13 14 behavior towards the *floor* limits v 15

31 and \blacksquare if \blacksquare 32 *I*. Appendix **B**

22 Table 8: Each setup (first column) is base

 24 characterization is discussed in each of the column, as also shown by to Table 1 criteria. Best setup in italics. Notes: * 25 25 and 26 an 26 Each "first servers" group can be composed of two or three servers according to Section 3.3 criteria, so the semicolon 27 28 separates the value for each of them.
29