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Recent Trends in 3D Concrete Printing

The emphasis on reducing construction time and production costs influence the construction process that has led us to investigate a new paradigm, known as 3D concrete printing. 3D printing has paved the way for a more sustainable manufacturing process in many industries by enabling the production of design-optimized and lightweight component. Due to its additive nature, this process uses material only when needed, saving a lot of production costs on material waste. Recently, there has been a significant increase in the number of publications and projects in 3D concrete printing applications.

Trend in the industry

In recent years, there has been an increase in the number companies that diverted from the primary business to work on 3D concrete printing and new start-up that focus primarily on 3D concrete printing. The pioneers in concrete printing were Contour Crafting, Winsun, Cybe Construction, XtreeE, Apis Cor. More recently, there has been a significant increase in the number of companies that provide concrete printing service such as COBOD, Be More 3D, ICON, Concreative and SQ4D. Figure 1 shows a list of concrete printing provider companies around the world. While the list in the figure may not be an exhaustive one, it certainly shows the significant growth in competition in this industry in recent years.

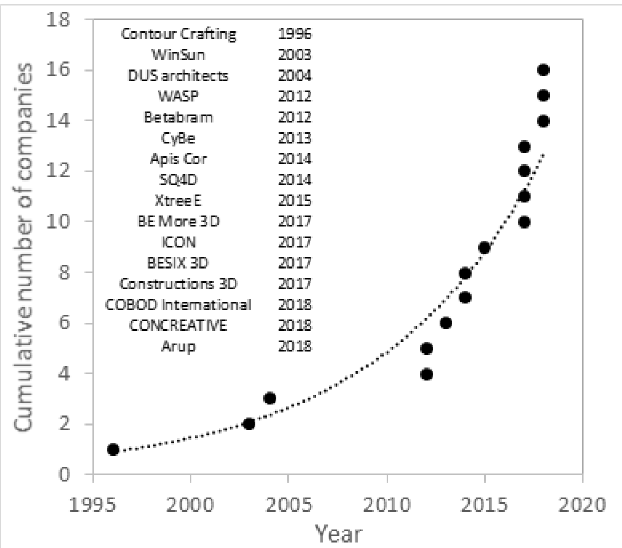

FIGURE 1 Growth in the number of concrete printing service provider over the years [1]–[10]

These companies use different types of construction printers such as gantry-mounted printers and robotic-arm mobile printer. While the programming language is different for these printers, the goal for all companies is the same which is to be the leader in the industry and to be able to push the technological boundary of concrete printing in the industry. Below are some of the projects that are worth mentioning.

Commercial projects

There were several commercial projects printed, from the bathroom to the commercial office to single-story building. Larger project such as 2-story villa was also printed in recent years. The focus is restricted to living habitat and does not include other construction projects such as bridges. The projects were getting more extensive and sophisticated, as shown in Figure 2. In the Netherlands, a micro-home was printed with sustainable bio-plastic, as shown in Figure 2 (a). The printed cabin walls are patterned with angular protrusion to create a 3D surface and give the building extra structural stability. When the cabin is no longer required, almost all of the material can be shredded and reused for another project [11].

FIGURE 2 commercial projects printed (a) Micro-home printed in bioplastic in Amsterdam (b) Pre-fabricated bathroom unit printed in Singapore (c) 2-story house printed in Belgium in one piece (d) 3D printed single-story house in Texas (e) Printed office in Dubai (f) 2-story villa printed in China with reinforcements [12]–[16]

In Singapore, a prefabricated bathroom unit (PBU) were printed in 2017 to showcase the capability to 3D print an unfurnished bathroom in less than a day shown in Figure 2 (b). After printing, the bathroom is furnished with toilet fittings ready for used in a construction project. This approach can reduce the manufacturing time by 30% and create PBU that are 30% lighter [15]. The complicated shape of a PBU and its walls can be developed and printed at a faster pace to satisfy the needs of the customer as no moulds were needed. Several single and double-story houses are printed in the US and Belgium, as shown in Figure 2 (c) and (d). These projects see a reduction in the project cost and a reduction in construction waste [13]. The use of cement is also common in these projects to maintain the sturdiness of the structure.

In China, a 3D printed public restroom was 3D printed from the infrastructure to the restrooms' decoration. Everything item was printed in the factory and was transported onsite where they were assembled. Due to this prefabricated process, only a few workers and a crane is needed for the assembly. This manufacturing process was similarly employed in the world's first 3D printed office shown in Figure 2 €. They were printed in China and shipped to Dubai for assembly. Such an approach cut the labour cost by 50% and the overall waste of construction by 30% [12]. Additionally, a two-story villa was printed in China on-site with reinforcement, as shown in Figure 2 (f). the reinforcement frame was erected before printing concrete over it. This project took 45 days to be printed. It was reported that the building could withstand up to a level eight on the Richter scale [16].

Trend in research

While 3D concrete printing is booming in the commercial industry, there is also a significant number of academic research developments. Tay et al. [17] presented a review showing the exponential increase in the research paper number in recent years. There have been numerous reviews on the trend of 3D concrete printing and the material and method used in the process.

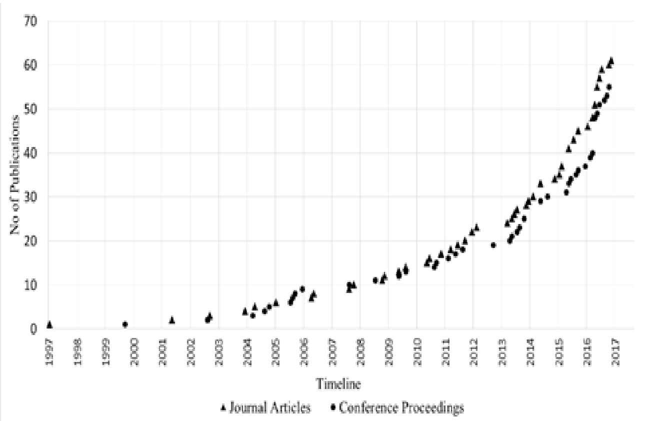

FIGURE 3 Number of publications over time [17]

Research Projects

There were several interesting research projects that were carried out in the area of 3D concrete printing. The few benchmarking properties that the pioneer researcher in the field first established were open time, extrudability, buildability and layer adhesiveness. Panda et al. [18] discussed the challenge of balancing the different benchmarking properties for successful printing of concrete. Liu [19] performed a numerical simulation on the concrete material flow to examine the printing parameter's effect on the filament during printing. It was found that uneven filament mass distribution at corners is obtained during the extrusion and deposition processes. For more uniform mass distribution, increasing the corner radius and relative nozzle travel speed while decreasing the nozzle aspect ratio is beneficial.

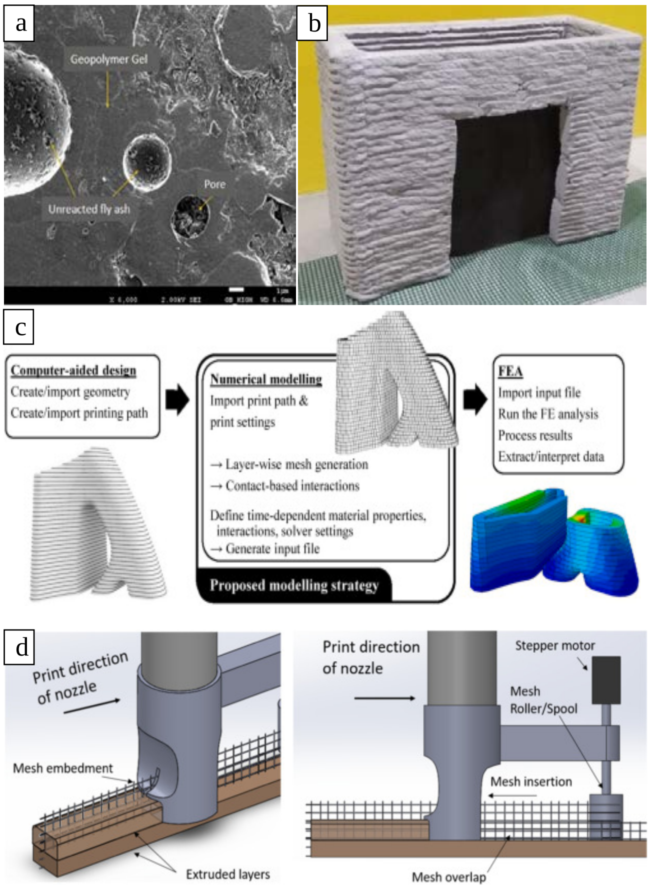

FIGURE 4 Different research around the world (a) (b) (c) (d) (e) [20]–[23]

Several researchers are working to formulate different concrete mixtures incorporating green material to reduce the concrete's carbon footprint. Panda et al. [20] developed a geopolymer, which replaces the cement completely, as a green construction material for large scale construction projects. Figure 4 (a) shows the scanning electron microscope (SEM) images of the geopolymer. Tay et al. [21] proposed a method to print overhanging structures by varying the printing parameters, as shown in Figure 4 (b). With different parameters, the printed support structure can have different strength, allowing the portion of the material below the overhang to be easily removed.

Ooms et al. [22] proposed a simulating strategy for the numerical simulation of 3D concrete printing. This simulation reflects the concrete's structural behaviour, giving an estimation of the failure height and failure mode during the printing process. Marchment and Sanjayan [23] have found a novel method to reinforce the different layers with a special nozzle, as shown in Figure 4. Such an approach allow curved structures to be printed with reinforcement.

Conclusion

The construction industry is among the main industries that contribute to the country's economic development. In many of the research, the innovative technical development of 3D concrete printing has been the outcome of cooperation between the industry and the university with the government's support. However, the use of 3-D printing is subjected to a few prerequisite requirements, such as its applicability in large-scale building projects. Additionally, the printed projects' life cycle performance remains unclear, and the degree of customization has yet been empirically examined in the construction industry. 3D concrete printing will reach its maximum potential in the construction industry when these challenges are addressed.

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Impact of Cognitive Tasks on Human Carbon Dioxide and Isoprene Emissions




Elliott Gall, Asit Mishra, Jiayu Li, Stefano Schiavon

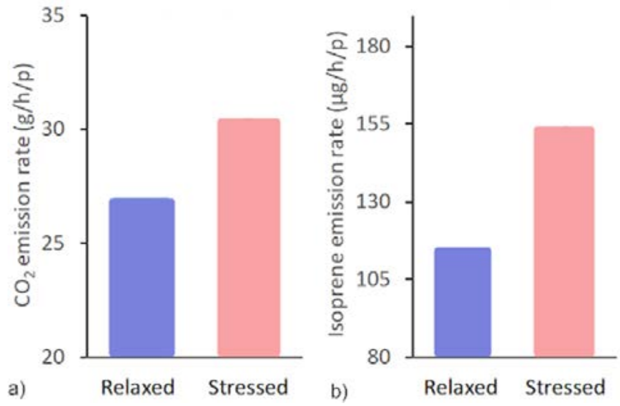

FIGURE 1 Plots of per person emissions for a) Carbon dioxide and b) Isoprene during relaxed (nature documentary) and stressed (cognitive tasks) periods.

Our bodies emit a variety of chemicals; when we are engaged in physical activity, we emit more of them - we breathe harder, we sweat more. Building standards prescribe ventilation rates to, among other objectives, remove odorous human emissions from a space. In buildings, we sometimes measure CO_2 because it is related to ventilation rate, number of people present, and their activity level. Building designers generally assume that human CO_2 emission rate depends on physical activity, but not on the level of mental effort. Can the cognitive effort we exert - like working in an office or studying in a classroom - affect our emission rate?

To examine the impact of cognitive tasks on human chemical emissions, we set up our state-of-the-art climate chamber to simulate a typical office environment with four participants engaged in two different activities:

1. Stressed condition: standard cognitive tasks (targeting their working memory, decision-making, task switching, etc., (Fig 1a) for 30 minutes
2. Relaxed condition: watching a 30-minute nature documentary (Fig 1b).

We tested 16 participants in a counterbalanced experiment, that is, half the participants started with the stressed condition and then did the relaxed condition and for the other half of the participants, the order was reversed. All other conditions were kept the same during both periods.

We sampled the air in the chamber and later analyzed it using gas chromatography mass spectrometry, focusing specifically on isoprene. We also obtained readings of certain physiological metrics of stress and cognitive effort from the participants - heart rate variability, pupil dilation, and salivary alpha amylase levels for each period. Carbon dioxide levels in the chamber were being continuously logged.

As expected, performing cognitive tasks raised all the physiological measures of stress we collected, as compared to watching the nature documentary. At the same time during the cognitive tasks period, the emission rates of isoprene and carbon dioxide from the participants increased substantially (Figure 1). This increase in emissions occurred irrespective of whether participants started first with cognitive tasks or with the nature documentary. So, hard cognitive work does indeed make you emit more CO_2 and isoprene! There are hundreds to thousands of organic compounds emitted by the human body - our study focused only on two prominent human chemical emissions: carbon dioxide and isoprene. Future studies can build on our work to measure these other compounds. With further studies, if we are able to relate more specific chemical emissions with cognitive workload (in addition to isoprene) we may one day be able to infer cognitive load on occupants based on air quality.

Since ventilation standards are often focused around human emissions, the higher emissions during mentally demanding tasks may require us to revisit the standards, especially for offices and classrooms. For example, based on our results, the ventilation would need to be increased by 12% to have similar indoor air quality (assessed by indoor CO_2 levels during cognitive tasks as was during watching the nature documentary). An alternative is to dynamically control the ventilation rate based on the carbon dioxide level measured in the room.

Reference

Gall ET, Mishra AK, Li J, Schiavon S, & Laguerre A. 2020. Impact of Cognitive Tasks on CO_2 and Isoprene Emissions from Humans. Environmental Science & Technology. https://doi.org/10.1021/acs.est.0c03850

Open-source version:
https://pdxscholar.library.pdx.edu/mengin_fac/324/

Upholding the Smart Grid Defense Security in 5 Steps

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The future of energy systems would be driven by digital technology that would enable a smarter and more resilient grid. For instance, implementation of smart metering devices and bidirectional communication would improve electricity grid's reliability, efficiency, and flexibility. However, the new technology has complicated the existing protection system. Thus, resulting in the grid to be more susceptible to cyber-attacks, which could be regarded as the biggest challenge. Consequently, a series of cyber-attack events have had occurred over the past decade, such as Stuxnet (2010) and Triton (2017). These cyber-attacks have demonstrated to be sophisticated, advanced and could lead to severe consequences on grid operation, system operators, consumers, and regulators. Subsequently, this catastrophe could result in equipment damage, large scale blackouts, economic impacts, and it required significant financial resources to resolve these cyber-crimes. We do not want these security risks to impede trust, resilience and prevent the grid from realizing its fullest potential. Thereby, this has become a task of paramount importance to keep up with the latest advances along this research frontier to ensure a trustworthy and resilient energy network as the grid transforms.

Security Framework A security framework is required to review the existing defence solutions and issues in the smart grid. This framework aims to reduce the risk of threats occurring and impacting, ensuring system security. Besides, a framework will allow the conceptualization of complex issues in a broader context. With a more strategic review and precise understanding, the framework will build a thorough security program for the system. As such, we have adopted the cybersecurity framework from the National Institute of Standards and Technology (NIST), and it has five fundamental functions - Identify, Protect, Detect, Respond, and Recover [1]. The cycle of this framework is repeatable, allowing identifying gaps in the current risk approach and developing a road map for further improvements.

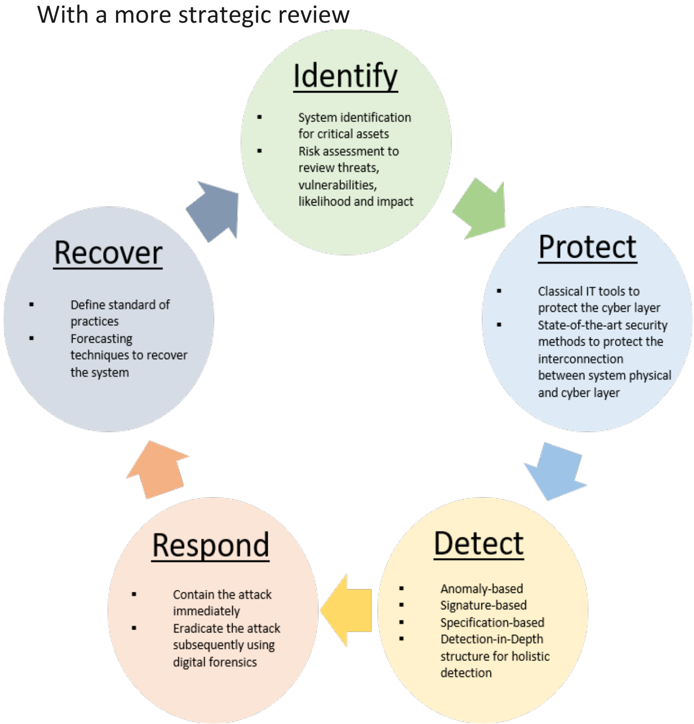

FIGURE 1 Framework for Improving Critical Infrastructure Cybersecurity

Identification The first component of the framework is identification and has two parts. First, recognizing the operations of the system to provide identification of critical assets. The system assets can be categorized into four different layers - physical system, device, communication, and management. This classification helps to provide a foundation and a more precise understanding of each layer's security issues. Thus, allowing the defender to understand what defence strategies to be incorporated in these layers to ensure system stability and reliability. Secondly, performing a risk assessment to review the threats, vulnerabilities, likelihood, and impact of attacks on the system [2]. A threat is an intent and method targeted at exploiting a vulnerability. Assessing the system's vulnerabilities then allows a defender to know what are the existing security controls. Besides, based on the four different layers, one can identify the plausible loopholes within each layer. Subsequently, the likelihood of an attack can be evaluated based on the identified threats and vulnerabilities. The likelihood is a risk factor that estimates the probability that a threat might occur by exploiting a given vulnerability and the possibility that the threat results in adverse impacts regardless of the magnitude of harm. The final step of the risk factor is to evaluate the impact on the system. Simulation and experimental studies must be performed to understand how cyber-attacks impact the system and measure its impact. The risk assessment allows the defender to design or invest explicit protection measures in the complex grid system. Conclusively, this section of the framework will provide fundamentals for developing the security solutions for the system.

Protection

A defender can then plan and implement suitable protection tools after evaluating the risk in the system. Similarly, the system protection layers can be split into the four identified layers to isolate and prevent attacks from propagating to other parts of the system. Traditionally, security was never a primary concern for the grid. The grid was only designed to protect against faults using circuit breakers. Besides, there are tools such as encryption and authentication to protect the network against attacks. However, these classical IT solutions possess vulnerabilities like latency issues that could destabilize the system and are insufficient to protect the system against attacks on the cyber-physical system. Hence, in response, there is a need to develop and apply new state-of-the-art security methods to protect the interconnection between the system's physical and cyber layers.

Detection If the attack has successfully bypassed the protection measures, the system must have tools to detect anomalies. There are three main types of detection methods for anomalies in the cyber-physical grid, namely anomaly-based, signature-based, and specification-based. The signature approach detects attacks when the system behaviour matches an attack pattern stored in a signature database. This method is useful in identifying known attacks but unable to detect new threats. The anomaly approach detects malicious activities when the monitored data deviates from normal behaviour. However, it usually suffers from high false-positive error. The specification-based approach is similar to anomaly-based. Besides, it has a set of pre-defined rules used to compare with the system's normal behaviour. This method has a lower false-positive rate and can detect new attacks. However, the strength depends on the accuracy of the selected specifications. As there could be a wide range of attacks, there is no single solution to detect attacks in the entire system. Instead, a Detection in-Depth structure with multiple layers of detection tools need to be in place. We can classify these layers as entry- or system-levels. Within each layer, it will be designed uniquely to serve a specific purpose to protect the system. The entry-level detects for anomalies in the attacker entry points such as metering devices or networks. The objective is to validate the integrity of the data. However, there could still be other loopholes in the system, and it is impossible to detect at every point. Besides, the attack vector might already be in the system. Hence, it is crucial to include another layer of defence. The system-level aim is to detect the remaining attacks that are unidentified in the first layer. The detection algorithms must be generalized and not specific to a single type of attack vector and must detect unknown attacks. As we can use physics based mathematical models to describe the power system, it can be used to understand the system's dynamics for developing a generalized algorithm to detect attacks when the signals deviate from their normal range.

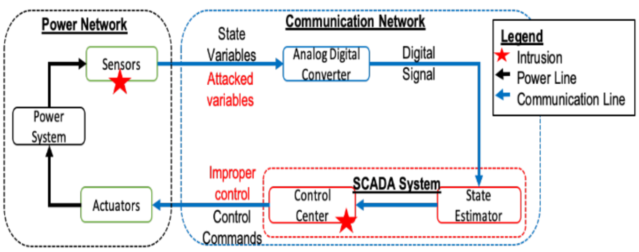

FIGURE 2 Cyber-Physical System Vulnerabilities

Besides, physics based approach is real, and it makes human feel comfortable with the proposed solution. Conclusively, this detection in-depth structure, coupled with multiple solutions at various levels, will improve the system's resiliency and restrict potential severe damages.

Response Upon detecting an attack, it is crucial to respond to prevent the attack from propagating. As the grid is an essential service, it is impossible to shut down the entire system for investigation. Hence, the response function splits into two parts - containing the attack immediately using suitable response tools, and subsequently eradicating the attack using digital forensics tools. It is crucial to assess the impact before suggesting suitable strategies for an immediate response. As the severity could range from mild to severe cases, solutions will be unique for every attack detected. It is also vital to assess these solutions to ensure its effectiveness in maintaining the grid's resiliency. The next step is to eradicate the attack. Digital forensics must be deployed to locate the attack source, recreate the attack signal, and recover the data loss. Subsequently, new measures can be proposed to secure these vulnerabilities and prevent similar attacks from occurring. As the common goal of digital forensics is to have a clearer understanding of an event of interest by finding and investigating the facts related to the event. Digital forensics could be performed using the four-phase process - Collection, Examination, Analysis, and Reporting [3]. However, digital forensics still poses a myriad of challenges before it can be successfully deployed in the smart grid. For instance, communication links for data acquisition must be secured. Next, sufficient storage capacity must be made available to store a high volume of data. Data must not be compressed as contents that may be useful might be lost. Besides, some of these data are volatile, and the legacy equipment in the system might not be capable of supporting digital forensics.

Recovery The last step of the framework is to revert the system to its previous operation, if not its best possible status. As the trust no longer exists between parties, we need to either resolve the attack and protect the vulnerability to re-establish the trust using digital forensics or propose other methods to ensure continuous operation of the system. For example, if the measurements are affected, or the control center are blinded to perform control actions, it will be useful to use forecasting techniques to aid in the recovery process. However, there is still a lack of concrete standard of practices to how the system to recover from an attack.

To sum it up, it will be beneficial that research studies on security are performed using the NIST framework to ensure a continuity, and holistic defence system for the smart grid.

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pythermalcomfort: A Python package for thermal comfort

Federico Tartarini, Stefano Schiavon

Federico Tartarini and Stefano Schiavon led the development of pythermalcomfort a Python package (Figure 1) that allows users to calculate the most common thermal comfort indices in compliance with the main thermal comfort standards such as ASHRAE 55 and ISO 7730. For example, pythermalcomfort can be used to calculate: Predicted Mean Vote, adaptive models, Standard Equivalent Temperature, local discomfort, clothing insulation, and psychrometric properties of air.

pythermalcomfort allows researchers and professionals to accurately perform complex thermal comfort calculations in Python without the need of re-writing the programming code. pythermalcomfort together with CBE Thermal Comfort Tool are free open-source tools designed and developed by CBE and SinBerBEST which aim to translate research findings into practical industrial applications. With Python being among the most widely utilized programming languages and pythermalcomfort being the only Python library which includes a comprehensive list of thermal comfort functions, we believe that pythermalcomfort will have a significant impact in both the research and industrial communities.

Federico Tartarini and Stefano Schiavon released the code open-source under the MIT licence, published a paper in which they describe the software, and developed documentation, examples and video-tutorial to guide users on how to use this package. All pythermalcomfort functions have been validated against the reference tables provided in the corresponding thermal comfort standards.

Motivation and significance

People spend the great majority of their time indoors. Indoor thermal environmental conditions significantly affect people well-being, performances and the overall satisfaction with the built environment. Consequently, researchers have developed, and tested a series of indices to assess the quality of the indoor thermal environment. Among these models, the Predicted Mean Vote (PMV), the adaptive thermal comfort models, and the SET have been widely adopted by researchers and practitioners worldwide. These models are now included in many National Building Codes and in International Standards such as the ASHRAE 55-2020, EN 16798-1:2019, and ISO 7730:2005. They are aggregate models, which means that they aim to predict how a group of people would perceive their thermal environment indoors in terms of given environmental (i.e., relative humidity, dry-bulb air temperature, air speed and mean radiant temperature) and personal (e.g., clothing insulation and metabolic rate) conditions. PMV is the

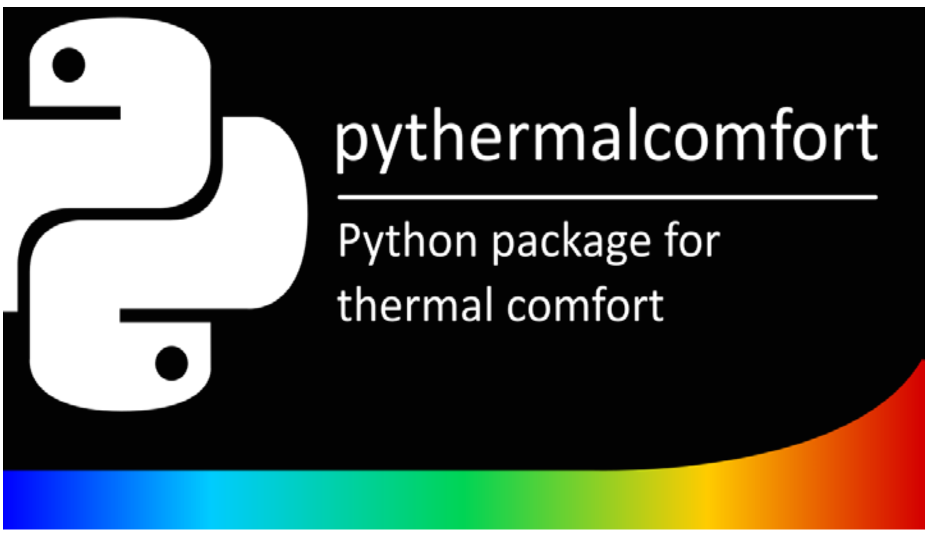


FIGURE 1
pythermalcomfort logo

reference index to assess thermal comfort conditions in mechanically conditioned buildings, while the EN and ASHRAE adaptive models are used to assess thermal performances of naturally conditioned buildings.

Programming codes to calculate the above mentioned indices are available in the ASHRAE 55 and the ISO 7730 Standards. However, they are either written in JavaScript or BASIC and the above mentioned Standards are not freely available. Consequently, even for a skilled Python user it may take a significant amount of time to access the code, re-write it and validate it against reference tables to ensure it does not contain errors. Making it an inefficient, long and error-prone process.

Python is a general purpose programming language which is gaining popularity non only among programmers but also among researchers. In 2020, it was one of the top five most used programming languages worldwide. While more than 200,000 packages have been developed for Python, we did not find a comfort package specifically designed for thermal comfort.

We, therefore, decided to develop pythermalcomfort to allow researchers and professionals who use Python to calculate all commonly used thermal comfort indices. We open-sourced the code so other users can contribute to our project or use it in their applications.

How to get started

pythermalcomfort can be freely downloaded from PyPI using the following command 'pip3 install pythermalcomfort.

Resources:

pythermalcomfort package repository:
https://pypi.org/project/pythermalcomfort/

Official documentation:
https://pythermalcomfort.readthedocs.io/en/latest/readme.html

Reference

Tartarini F, Schiavon S, 2020. pythermalcomfort: A Python package for thermal comfort research. SoftwareX 12, 100578. https://doi.org/10.1016/j.softx.2020.100578

eplusr: A framework for integrating building energy simulation and data-driven analytics

Hongyuan Jia, Adrian Chong

With increasing real-time sensing capabilities in buildings and cloud computing, digital twins of the built environment are becoming a real possibility. Consequently, the ability to integrate building energy simulation (BES) with state-of-the-art data-driven analytics is vital for predictive analytics, knowledge discovery, and generating useful insights. However, like most data scientists, energy modelers spend a bulk of their time cleaning and organizing data rather than refining algorithms or analyzing data.

To streamline simulation and data analytics workflow and facilitate reproducible simulations, we developed eplusr, an R package that allows seamless integration between the energy simulation program EnergyPlus and the abundant data analytics packages available in R. The eplusr framework is different from existing ones because of its data-centric design philosophy. Specifically, the objectives behind its development are (1) to provide better and more seamless integration between BES engine EnergyPlus and R-programming data-driven analytics environment and (2) to build infrastructures for portable and reusable BES computational environment to facilitate reproducibility research in the building energy domain. The framework consists of 3 components with different purposes (Fig. 1):

1. *I/O processors* for structuring BES inputs and outputs for seamless integration with data analytics workflow. We develop a unified tidy data interface to ensure all simulation data are always stored consistently. The data can be easily fed to various data mining and machine learning algorithms using R's existing tools.

2. *Parametric manager* for conducting flexible and extensible parametric simulations. It can be integrated with existing R tools to perform sensitivity analysis, model calibration, and optimization.

3. *Computational environment* based on Docker containerization to facilitate reproducibility research in the energy simulation domain. It provides an infrastructure for a portable and reusable computation environment. It has the scalability potential for large cloud-based BES computation.

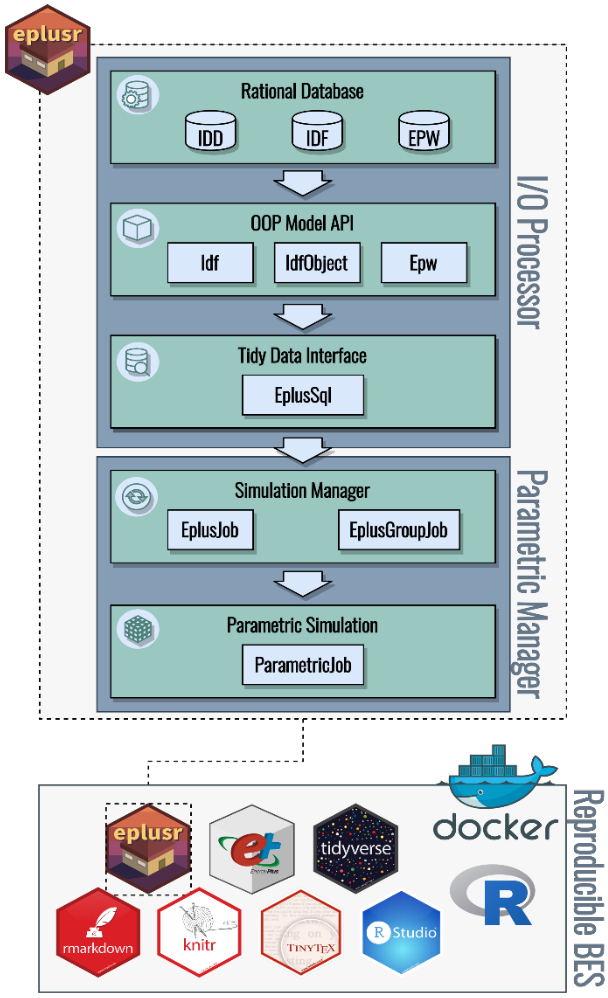


FIGURE 1 An architecture overview of the eplusr framework

The first 2 components have been packaged into a free, open-source, cross-platform R package eplusr distributed using CRAN (The Comprehensive R Archive Network). The third component is distributed using Docker Hub

Fig. 2 shows an example of tidy BES output using the tidy data interface. Table (a) is the standard output format of an EnergyPlus CSV, and Table (b) is its tidy representation. The concept of tidy data was first proposed by Wickham (Wickham 2014) as a standard way of mapping the meaning of a dataset to its structure. This structure makes it intuitive for an analyst or a computer to extract needed variables. It is particularly suited for vectorized programming languages like R. Considering the times of data analysis operations to be performed on the values in a variable, the advantage of structuring values in a standard and straightforward way stands out. It can facilitate initial exploration and analysis of data and simplify the development of data analysis tools that work well together.

(a)

KeyValue Name Units Frequency

	Date/Time	Key1: Variable1 [J] (30-min)	Key2: Variable1 [J] (Hourly)	Key1: Variable2 [W] (30-min)
1	m/d H1:00	value1	value5	value7
2	m/d H1:30	value2	NA	value8
3	m/d H2:00	value3	value6	value9
4	m/d H2:30	value4	NA	value10

Tidy Data Interface

(b)

	Month	Day	Hour	Minute	KeyValue	Name	Units	Frequency	Value
1	m	d	H1	0	Key1	Variable1	J	30-min	value1
2	m	d	H1	30	Key1	Variable1	J	30-min	value2
3	m	d	H2	0	Key1	Variable1	J	30-min	value3
4	m	d	H2	30	Key1	Variable1	J	30-min	value4
5	m	d	H1	0	Key2	Variable1	J	Hourly	value5
6	m	d	H2	0	Key2	Variable1	J	Hourly	value6
7	m	d	H1	0	Key1	Variable2	W	30-min	value7
8	m	d	H1	30	Key1	Variable2	W	30-min	value8
9	m	d	H2	0	Key1	Variable2	W	30-min	value9
10	m	d	H2	30	Key1	Variable2	W	30-min	value10

FIGURE 2 An example of tidy BES output data representation using tidy data interface

The framework's parametric manager provides a set of abstractions to ease parametric model generation, design alternative evaluation, and large parametric simulation management. It is designed to be simple yet flexible and extensible. One good example of the extensibility is the epluspar R package, which provides new classes for conducting specific parametric analyses on EnergyPlus models, including sensitivity analysis using the Morris method, optimization using Genetic Algorithm, and calibration using Bayesian Theory.

A successful BES reproducible research contains two major components: (1) the building energy models and (2) the code to perform simulations and data-driven analytics. However, computer environments are complex and often change rapidly. It is very challenging to reproduce the same workflow and results even you have the original data and code. We developed a reproducible BES computational environment based on the Docker containerization technology in the framework to address this issue. It captures the full software stack, including all software dependencies, into a portable and reusable image.

We included four groups of toolchains needed for common BES and data-driven analytics workflows using the eplusr framework:

1. Statistical computing environment, including the latest R environment and RStudio Server, a web-based integrated development environment for R programming
2. BES engine, including EnergyPlus of specified version and the eplusr R package
3. Data analytics toolkits, including a collection of tidyverse R packages for data import, tidying, manipulation, visualization, and programming
4. Literate programming environment, including R Markdown related packages for dynamic document generation

The proposed BES computational environment can be easily adapted to any R-centric workflows and enables researchers in the BES field to build and archive reproducible analytics. Further evolutions can be taken to make the computational environment tailored to different audiences and use purposes.

The absence of seamless integration of BES and data-centric analysis raises problems in both the productivity and the credibility of BES studies. eplusr bridges the gap between the building energy simulation and data science domains. We believe the open-source nature of the eplusr framework will advocate the BES domain to embrace the tools essential for maintaining a reproducible workflow.

Reference

Hongyuan Jia and Adrian Chong. 2020. eplusr: A framework for integrating building energy simulation and data-driven analytics. Accepted in Energy and Buildings.
Hadley Wickham. 2014. Tidy Data. Journal of Statistical Software 59 (1): 1–23

Prof. Panda Elected to IEEE Fellow

Congratulations to Associate Professor Sanjib Kumar Panda who has been elevated to IEEE Fellow for contributions to iterative learning control of motor drives.

Sanjib current research focuses on the development of novel computational intelligence-based models and methodologies to aid the integration of the new Smart Grid technologies into the existing infrastructure so that power grid can effectively utilize pervasive renewable energy generation and demand-side management programs, while accommodating stochastic load demand. He has published more than 450 publications which have been highly cited. Sanjib current research interests are in energy harvesting, both at high-power level as well as at very low-power level for wireless sensor nodes and networks, control of renewable energy sources generation and integration to utility-grid, energy storage devices integration with grid, condition based-, preventive- and predictive- maintenance of electrical infrastructures, critical assets management, demand-side response, transactive energy framework in buildings, smart-electrical socket outlets, etc.

He has been a very active member of the Institute of Electrical and Electronics Engineers (IEEE). Sanjib has served in various capacities as the Chapter Officer in the IEEE Singapore Section Joint Power Electronics and Industry Applications Society Chapter, and also as the Chair of the IEEE Singapore Section. He was awarded the Best Volunteer Award by the IEEE Singapore Section in 2006 and IEEE R-10 Best Volunteer Award in 2014. Presently, Sanjib is serving as the R-10 Membership and Chapter Development Chair for the IEEE Power Electronics Society.

SinBerBEST Awards 2020

The SinBerBEST awards have taken on an increased importance this year: coming at a time when many of us have had to radically adapt the way we work to respond to the pandemic. While we could not give the awards in a face-to-face session during the symposium this year, we continue with our tradition of acknowledging excellence and outstanding work.

For this year, the Best Paper Award goes to:
Radhakrishnan KK, Chinh HD, Gupta M, Panda SK, Spanos CJ, " Context-Aware Plug-Load Identification Towards Enhanced Energy Efficiency in the Built Environment," IEEE Transactions on Industry Application.

The Outstanding Young Scientist Award goes to
Dr. Baihong Jin.

The Outstanding Project Achievement Award goes to the
BCA Living Laboratory Project

The Distinguished Support Award goes to
Ivanna Hendri

Congratulations to all the winners!

Arrivals and Departures

1. Wu, Zhibin Postdoctoral Scholar May 2020
2. Martin, Miguel Postdoctoral Scholar Nov 2020
3. Gu, Lei Research Fellow NTU, Nov 2020
4. Tay, Daniel Research Fellow NTU, Oct 2020
5. Jin, Baihong Research & Development Engineer, Nov 2020

A. Asit Mishra Postdoctoral Scholar Dec 2020.

B. Konandur Rajanna, Viveka Postdoctoral Scholar, Jan 2021

C. Huang, Judy Administrative Officer, Dec 2020

D. Hendri, Ivanna Design Engineer, Dec 2020

Impact of free and online thermal comfort tools

Our open-source tools are helping thousands of engineers, architects, researchers, educators, facility managers, and policymakers worldwide to better understand how to design and operate buildings to enhance thermal comfort conditions indoors while minimizing energy consumption.

SinBerBEST in collaboration with CBE at UC Berkeley recently upgraded the CBE Thermal Comfort Tool and released the pythermalcomfort Python library. The former is a free online tool for thermal comfort calculations and visualizations (Tartarini et al, 2020a) the latter is a Python package that allows users to calculate the most common thermal comfort indices (Tartarini et al., 2020b). Both tools comply with the major international thermal comfort standards (ASHRAE 55–2017, ISO 7730:2005, and EN 16798–1:2019).

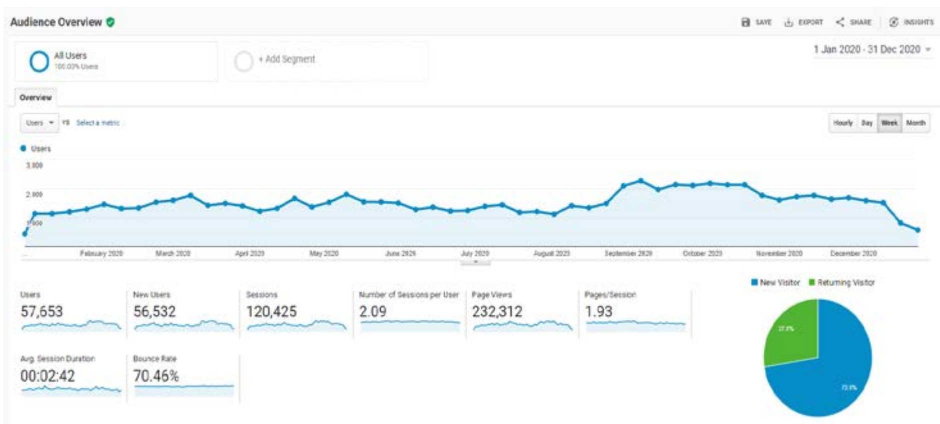
In 2020 (1 Jan - 31 Dec) the CBE Thermal Comfort Tool was used by 57653 unique users worldwide. The tool was widely used in Singapore where a total of 1052 unique users utilized our tool.

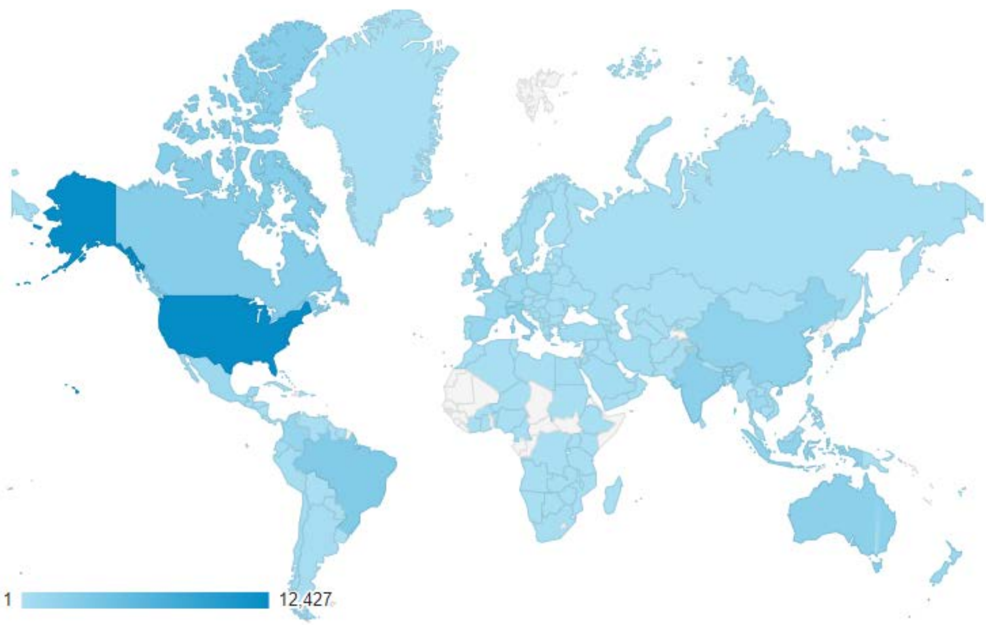
Pythermalcomfort was first released in March 2020. In July 2020 we published an open-access manuscript describing the tool. From Jul 2020 and Jan 2021 approximately 1700 people access the Python package official documentation. Approximately 2% of them were Singaporean users. Pythermalcomfort was downloaded more than 31000 times between March 2020 and Feb 2021.

Reference

Tartarini, F., Schiavon, S., 2020a. pythermalcomfort: A Python package for thermal comfort research. SoftwareX 12, 100578.
https://doi.org/10.1016/j.softx.2020.100578

Federico Tartarini, Stefano Schiavon, Toby Cheung, Tyler Hoyt, CBE Thermal Comfort Tool: Online tool for thermal comfort calculations and visualizations, SoftwareX, Volume 12, 2020, 100563, ISSN 2352-7110, https://doi.org/10.1016/j.softx.2020.100563.





Interview with Dr. Federico Tartarini

Dr Federico Tartarini is a SinBerBEST postdoctoral scholar. He conducts research in the field of human comfort and building nexus. We asked him about his past experience, current research and their hopes for the future.

Can you briefly describe your education background?
I completed both my bachelor and my master of science degree in energy engineering at the University of Bologna, Italy. During my master degree, I had the great opportunity of studying abroad twice. Thanks to the EU Erasmus Exchange project, in 2011, I was able to study for one full semester at the Technical University of Copenhagen, Denmark. I was also awarded with a scholarship from the University of Bologna that allowed me to write my Master’s thesis at the University of Wollongong, Australia.
After completing my master degree, I worked for a year as an energy consultant in Italy and in 2014 I started my PhD at the University of Wollongong, Australia. The aim of my PhD was to analyse the impact of indoor environmental quality factors on the quality of life of occupants (staff and residents) and agitated behaviours of residents at several aged care facilities.

How did you get into this field?
I would like to thank my university Professor Gian Luca Morini who sparked in me a passion for studying how to improve environmental quality and energy efficiency of buildings. He taught me the fundamentals of thermal comfort, building physics, and heating, ventilation, and air conditioning systems.
My interest for this field grew stronger throughout my master degree. This is one of the main reasons why for my master’s thesis project, I decided to join the Sustainable Building Research Center and help them to design and model an Indoor Environmental Quality Test Facility for the at the University of Wollongong, Australia.
Finally, my interest for this field fully developed during my PhD studies. This period of my academic career allowed me to dedicate all my efforts in trying to determine how occupants of aged care facilities, especially residents with dementia, perceive their environment. Professor Paul Cooper and Professor Richard Fleming my PhD supervisors helped me grow significantly as a researcher in this field and to consolidate my knowledge.

After completing my PhD, I always been working in this field of research and I am very passionate about it. The focus of my work, as a postdoctoral scholar, has mostly been on thermal comfort, Indoor Environmental Quality (IEQ), Heating Ventilation and Air Conditioning (HVAC) systems and development of non-intrusive methodologies to monitor IEQ parameters.

What drew you to SinBerBEST?
The opportunity of working at SinBerBEST had evoked my interest since when I initially heard about this research group from Professor Stefano Schiavon during a meeting we had in 2018 at UC Berkeley. I travelled to the US on my way home to Australia after attending the Annex 69 meeting “IEA EBC Annex 69 Strategy and practice of adaptive thermal comfort in low energy buildings”. During that trip I decided to stop in San Francisco and visit UC Berkeley. I then had the opportunity of meeting with Professor Schiavon. We discussed my past research, research interests and future goals, and he described all the projects he was working on. I then quickly realised that I wanted to be part of his team and join SinBerBEST.
SinBerBEST is one of the most reputable research program in the world. Stefano and his team are at the forefront of research on several field including sustainable building design, indoor environmental quality, and thermal comfort.

How does your work at SinBerBEST build on your past research?

My current work builds on my previous research on thermal comfort, building physics, and heating, ventilation, and air conditioning systems. At SinBerBEST I was able to work on a variety of projects, including but not limited to: testing the impact of smart and innovative cooling technologies on occupant perceptions, indoor environmental quality and energy consumption in buildings; development of personalized thermal comfort models for people living in the tropics; developing open-source thermal comfort tools; and smartwatch platforms for human comfort data collection.

I would have not been able to work on the above-mentioned projects without me having a strong background in this research field. My work at SinBerBEST is allowing me to significantly improve my background knowledge, expertise in this field of research and allowing me to grow as a researcher.

How can your research benefit people working in the building and other industries?

My research has several practical applications. As I have previously mentioned I have helped with the developed of two open source tools: pythermalcomfort a Python package for thermal comfort, and the CBE Thermal Comfort Tool a web-based tool. More information about the former tool can be found in an article of this periodical. These tools can be used by researchers, practitioners, policymakers and the general population to better understand how environmental and personal parameters affect how people perceive their thermal environment.

I also worked on the development of Cozie a smartwatch application that can be installed on both Fitbit smartwatches and the Apple Watch. We also open-sourced this project. Cozie and can be used by facility managers, researchers and building owners to better understand how building occupants perceive their indoor environment. Cozie allows building occupants to provide feedback about their environment in real time via their wearable devices. Data collected can be used to tune and improve the operation of buildings.

I recently conducted a study which aimed to developed personalized thermal comfort models using wearable and IoT devices. I am currently analysing the results and planning to publish them soon in peer reviewed journals. Results will help to better understand how people perceive their indoor environment.

I assisted and supported the SinBerBEST team during the construction and commissioning of the "Greenest building" in Singapore. A net zero energy building for the Singaporean Building and Construction Authority (BCA). In February 2021 we are planning to start a field experiment which aims to determine the positive impact that SinBerBEST technologies have on occupant perception, IEQ and energy consumption. I also worked in collaboration with BCA to develop a new Green Mark compliance path for building which use “Elevated air speed” indoors to enhance comfort conditions and reduce energy consumption.

What are your longer term goals?

My main long term goal is to keep growing as a researcher in this field, and to conduct and publish high-quality research. I also aim to keep developing open-source tools that can be freely used by other researchers, practitioners and the wider community to improve energy efficiency and indoor environmental quality in new and existing buildings. This will allow me to translate into practice my research findings and will help my research to reach a wider audience.

SinBerBEST

The SinBerBEST program, funded by the National Research Foundation (NRF) of Singapore, is a research program within the Berkeley Education Alliance for Research in Singapore (BEARS). It comprises of researchers from University of California, Berkeley (UCB), Nanyang Technological University (NTU) and National University of Singapore (NUS). SinBerBEST's mission is to advance technologies for designing, modelling and operating buildings for maximum efficiency and sustainability in tropical climates. This newsletter, published quarterly, is to showcase the excellence of SinBerBEST faculty, post doctoral fellows and students.

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