Simulation and Visualization of Virus Transmission for Architectural Design Analysis

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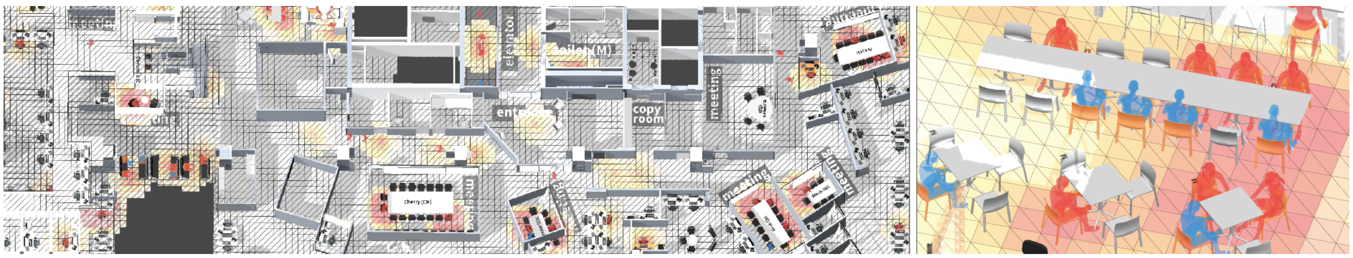

Figure 1: A multi-agent occupancy simulation for analyzing the risk of virus transmission from a longitudinal perspective.

ABSTRACT

The COVID-19 pandemic has made virus transmission a significant factor in designing buildings to ensure a safe and resilient environment. Simulation has been applied to analyze the potential risk of virus transmission within built spaces. Still, most existing simulations focused on a small region of the building, over a short period of time. Here we cover how we leveraged an occupancy simulation to inform and visualize the longitudinal impacts of virus transmission, in relation to a given building design and associated dynamic occupant behaviours. The flexibility of our system makes our simulation scalable and adaptable so that it can be applied to any building or context, with various types of occupants.

CCS CONCEPTS

• **Computing methodologies** → **Modeling and simulation**.

KEYWORDS

simulation, virus transmission

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1 INTRODUCTION

The design of the built environment and the interactions therein, influence the spread of viruses throughout space and time [West et al. 2020]. Infected occupants disperse virus particles into the environment via respiratory activities (e.g., *breathing*, *speaking*); then, the released virus particles diffuse through the building depending on the architectural layout. Virus particles deposited on surfaces can also be transferred to other surfaces via occupants' hands through *touch*. All these interactions depend on the dynamic behaviours of occupants in the built environment throughout the day.

Virus transmission in buildings is complex, and combining interacting mechanisms into a single simulation remains a challenge. To help solve this problem, we leveraged a game engine to simulate virus transmission. Game environments lend themselves naturally to the formulation of the *virtual world* as a replica of the *real world* for both buildings and virtual humans in 3D. We prepared a framework for architects and designers to import their designs to use as test-beds, apply multi-agent occupancy simulation based on a target industry or context, and simulate virus transmission through modelled air spaces and surfaces. Our approach complements previous simulations by illustrating virus transmission within the built environment from a longitudinal perspective, so that designers can predict otherwise potentially unseen risks in advance.

2 MULTI-AGENT OCCUPANT SIMULATION FOR VIRUS TRANSMISSION

Existing virus transmission simulations have typically focused on relatively small spaces (e.g., meeting room) over a short-term period [Shao et al. 2021; Wilson 2020]. We aim to extend the system to cover longitudinal aspects of human behaviours at an *architectural*-scale.

2.1 Occupant Behaviour Simulation

Human behaviours constitute a crucial aspect of virus transmission in the built environment (e.g., touching the built environment and breathing while moving around). Data from outbreaks show herd infection cases have been caused by touching shared surfaces (e.g., elevator buttons) throughout the day, or by breathing inside an enclosed area where an infected individual is, or once was. Still, these micro-behaviours and their long-term inter-relationships have been excluded from existing virus transmission simulations.

To help simulate more realistic virus transmission, we first leveraged a multi-agent occupancy simulation in a 3D building model to include the dynamics of human behaviours. Our system simulates virtual agents, making them behave based on the context, building geometry, and their customized roles. In addition to moving around the building (state-machine scheduler with a transition-matrix), agents also exhibit contagion-related behaviours, such as breathing, sneezing and coughing, each of which occurs based on a transition probability per time-step using average time intervals at each behaviour state.

2.2 Virus Transmission Simulation

Studies of virus transmission within physical spaces have often restricted their scope to either air-based or surface-based transmission routes. Including both pathways is pertinent for simulations for COVID-19, particularly given the persisting uncertainty of the role each might play in the current pandemic. Therefore, we tracked *contamination* values for each element in the building environment (air, objects, hands, lungs), which refer to the number of virus particles (virions) either on or within that element. If left alone, contamination *decays* based on a material-dependent rate. Occupant behaviours can also cause the contamination to change.

2.2.1 *Air-based.*

The '*air*' in our model is divided into grid cells, each of which stores the contamination value of the air above it. When an air-based contagion behaviour is triggered for an *infected* agent, the system spreads a different number of virions for each behaviour (e.g., *breathing* or *talking*) from the location of the occupant to the surrounding cells. If located within a contaminated cell, the occupant will inhale a proportion of the virions from the air. The system keeps track of the contamination value of each cell, and updates the value based on diffusion and decay.

2.2.2 *Surface-based.*

Various *objects* (e.g., desks, counter tops, appliances), *hands*, and *faces* are modelled as surfaces with *contamination* values that update due to direct touch interactions. Different *virus transfer load* parameters were used depending on the material. Behaviours related to cleaning and sanitizing reduce the contamination level of that surface to zero.

2.3 Configurable Simulation Input

To enhance the applicability of our simulation, providing high flexibility for customizing the simulation is essential. We extended the editor to offer control over agent variations (e.g., roles, health, mask wearing), virus specifications (e.g., half-life, virus transfer load), and initial environment settings (e.g., grid size, architecture design). At each simulation step, the simulation controls the occupants and their behaviours based on given parameters, layers the corresponding virus transmission on those behaviours, and updates the contamination of all objects. We provided default values for each parameter, based on data collected from the literature, to model behaviours and the virus in a realistic way.

2.4 Visualizing Virus Transmission

We applied a situated visualization technique on the 3D building, so that users can understand virus transmission in relation to complex environmental aspects. Whereas existing virus transmissions were visualized as a vector field (air flow) or particles with micro-details, our goal is to present an overview of virus contamination levels across a floor of a 3D building. Therefore, we applied a gradient shader that visualizes each cell's contamination value. The contamination of surfaces (e.g., objects, hands) and occupants' lungs were represented in a similar way, using a gradient mesh-shader on the 3D model of the objects.

3 LESSONS LEARNED

While we successfully made our initial step in utilizing a multi-agent occupancy simulation for virus transmission analysis, there are several critical takeaways. First, conveying the *dynamics of human behaviours* is valuable, but care must be taken to move towards simulation-driven design 'analysis'. Although our base behaviour simulation framework could provide other space occupancy information beyond virus transmission, including acoustic measures or social comforts, its critical limitation is that each run only demonstrates one of many possible outcomes. Aggregating the results of multiple simulation runs should help one analyze overall trends while still accounting for real-life dynamics.

Second, a game engine helped us to quickly simulate real-world scenarios in a digital building; still, we separated the models of human behaviour and virus transmission from the game engine. An independent data format was used to manage configurability and dynamics. Having done this, we opened the possibility of crowd-sourcing datasets, making the system relevant for a large number of industries and buildings in the future.

Finally, the potential users of our system will not all be experts in epidemiology or simulation. Our initial evaluation study conducted with building facility managers and small business owners confirmed that the 3D representation of simulated results engaged them with each virtual scenario so that users can better understand the inter-relationships between the built environment, occupant behaviours, and virus transmission. We believe the integration of simulation and visualization with 3D virtual humans could lead to more widespread and informed decision making by all user groups interested in analyzing space occupancy.

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