

The Flavian Amphitheater (Colosseum) in Rome: An Excellent People-Mover?

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ABSTRACT

A commonplace in modern scholarship about the Flavian Amphitheater ("Colosseum") in Rome is that it was an excellent people-mover. According to the standard view, each spectator arrived at the games with a ticket denoting his seat, and even ticket-holders seated in the upper reaches of the cavea could supposedly reach their place rather quickly. Egress from the building at the end of the spectacles was also correspondingly quick and efficient. The purpose of the present project is to develop a formal quantitative model to test the validity of this opinio communis. To achieve the desired goal, the Advanced Computer Graphics Group of the University of Zaragoza, Spain, along with the Spanish-based company Light Simulation Lab, are working on the development of software for crowd simulation. Approximately fifty thousand synthetic actors, governed by Artificial Intelligence (AI) algorithms, will enter the Colosseum through the proper entrance, find their way around, and walk to their pre-assigned seats. The AI is based on state machines, under a perception-reasoning-action scheme. Non-deterministic behaviors can be added to a few random actors, or the characteristics of a given percentage can be altered to observe the effect on the crowd movement. Given the accuracy of the Colosseum model and the AI rules, it should be possible to identify the bottlenecks (if any) in the structure.

1. INTRODUCTION¹

The Flavian Amphitheater (conventionally known as the "Colosseum") was built in Rome in the 70s A.D. by the Emperor Vespasian, who dedicated the partially-built complex in 79, the year of his death. The main purpose of the Colosseum was to house the gladiatorial games which had come to be a typical feature of Roman culture in the imperial capital and throughout the Roman world (see Auguet, 1972). Other events recorded here include mock naval battles, animal hunts, and the execution of criminals. Its seating capacity has been estimated at between 40,000 and 73,000 spectators (Claridge, 1998, p. 278; Coarelli *et al.*, 1999, p. 103; Grant, 1967, p. 82; Luciani, 1990, p. 24; Lugli, 1969, p. 37-38; Platner-Ashby, 1929, p. 10; Rea, 1999, p. 45; for general information on the building, see Rea, 1993).

Since the late 1990s, the Cultural Virtual Reality Laboratory (www.cvrlab.org) has been working on a digital model of the Flavian Amphitheater (figures 1, 2) with the help of an advisory committee that includes Heinz Beste (German Archaeological Institute, Rome), Mark Wilson-Jones (University of Bath), and Lynn Lancaster (Ohio University).

During the course of creating the model, CVRLab Associate Director Dean Abernathy observed a possible bottleneck in the circulation pattern affecting the mass of spectators. This observation was unexpected since the Colosseum has the reputation of being an excellent people-mover. For example, in a publication of the Archaeological Superintendency of Rome, which is responsible for management of the Colosseum, Abbondanza wrote, "the complex system of ramps and passageways enabled the crowd to flow in and out with ease" (Abbondanza, 1997, p. 12). This view can be traced back for decades (cf. Coarelli, 2002, p. 186, "*le arcate a pianterreno, 80 in tutto, davano accesso alle scalinate che portavano ai vari settori della cavea: un sistema complesso, simile a quello degli stadi moderni, che permetteva la rapida evacuazione degli spettatori*" (Auguet, 1972, p. 41), "the purpose of the numbers engraved on the arcades becomes indeed obscure, without a definite system for seating the people, made the more necessary by the need to seat 50,000 spectators in a relatively short time;" (Lugli, 1969, p. 19) "[the architect] was also concerned with providing rapid access for the vast numbers of the public... Study of the overall design of the building shows how completely he succeeded;" (Cozzo, 1928, p. 246) "*era impossibile quindi che avvenissero intralci ed ingombri nella circolazione del pubblico; l'anfiteatro si riempiva e si vuotava nell'ordine più perfetto e più regolare, in quanto ogni ordine di gradus aveva gli accessi e le scale*").

The most quantitatively precise version is perhaps that found in Pearson, 1973, p. 80. "In engineering there are clear affinities between the control of water and of human beings in the mass. In the preliminary designs for the Colosseum, similar foresight was applied to both. One reason why the building has stood for centuries can be attributed to the drainage system hidden beneath the main piers, a carefully constructed line of gullies leading the surplus water from the perimeter to the main sewer. In much the same way the architect devised a system to ensure that his vast amphitheatre would fill and empty perfectly with people. He did this by planning eighty so-called *vomitoria* – a word which graphically sums up

¹ Diego Gutierrez and Francisco Seron were primarily responsible for sections 2, 3, and 4. Bernard Frischer was primarily responsible for section 1 of this paper as well as the bibliography. He also had the idea for undertaking the quantitative test of the bottleneck thesis.

the way the Colosseum spewed out its audience when the show was over – big numbered staircases leading the people to carefully segmented rows within the building. These staircases worked so efficiently that it has been calculated that a full audience could leave the building *in three minutes flat*” (our emphasis).

It is unfortunate that Pearson did not give a source for the calculation. The purpose of the present project is to develop a formal quantitative model to test Abernathy’s thesis that, for most spectators, passage from the entrance to a seat in the upper levels of the amphitheatre and from their seat to the exit was slower than previous scholars lead one to expect.

The suspected bottleneck can be seen in figure 3, a graphic illustrating the circulation routes through the structure. As the illustration makes clear, the routes to the best seats in the lower part of the *cavea* (yellow and green in fig. 3), where the citizens of higher status sat, were short and direct (on the principles of seating in the Colosseum, see Rea, 1993: 33). In contrast, the spectators who had seats at a higher level passed through a relatively low, narrow, and dark corridor (pink in fig. 3). There were no alternative routes: the overwhelming mass of spectators coming to the view the games had, perforce, to pass through this corridor. Passage through this least spacious and darkest corridor in the superstructure of the Colosseum cannot have been a pleasant experience, no matter the crowd density. One can imagine that it even served to slow down the flow of spectators to their seats (or, at the end of the day’s events, to the exits). The present study represents an attempt to take such observations and hypotheses based on eyeballing alone and make them more rigorous and quantitative.

2. ARTIFICIAL INTELLIGENCE FRAMEWORK

In this section we describe the Artificial Intelligence (AI) framework used in this project, introducing the terms and concepts involved. The approach taken in this work is bottom-up: we build a basic set of rules and study what happens, as opposed to a top-down approach where the goal dictates the behaviour rules. The bottom-up approach guarantees that the system is not deterministic, its outcomes cannot be predicted and therefore several unbiased scenarios can be tested.

The aim of this work is to develop a multi-agent AI system with scripting capabilities in order to detect possible bottlenecks in the building and to test several hypotheses. The simulation does not need to run in real time; it will be calculated off-line to be then output to a render engine for visualization purposes.

2.1 VIRTUAL AGENTS

In general terms, an agent is a software entity which is placed in an environment and operates under a continuous perception-reasoning-reaction loop with said environment. It then first receives as input some stimulus from the environment by using its own perceptual system, it processes it by adding the new information to its previous knowledge and goals and finally reacts by selecting one in a set of possible actions, which in turn might alter the environment, thus generating new stimuli. An agent’s basic structure is made up of:

- Senses: the way it perceives the environment
- Knowledge: a database about itself, its goals and the environment
- Intelligence (behaviour): decision-making capabilities based on the knowledge database
- Motor: mechanisms that allow the agent to modify itself and the environment. It represents the agent’s capabilities.

An attribute vector for each agent contains information about the agent itself and the environment. This information can be stored, deleted or modified during the simulation, and is the de facto database of the agent. The agents have an adaptive intelligence, where no previous knowledge of the environment is required.

The physical representation of the agent in the virtual world is called *avatar*. The description of the avatar then includes the software entity known as agent plus its graphical representation (animations, geometry, textures...) and its physics (weight, velocity, acceleration...). This allows the agent to modify the environment, including another agent.

2.2 HIERARCHICAL FINITE STATE MACHINES (HFSM)

The Hierarchical Finite State Machines (HFSM) contain the logic of the agent: depending on the state it is in and based on the changes in its attribute vector and/or environment, it will transition from one state to another, modifying both its attribute vector and the environment if necessary. To do this, the agent has a set of predefined actions, provided by the AI engine (walk, climb the stairs, stop...). Even though these actions are predefined, they are generic enough to allow for great flexibility in the behaviour of the agents. The term *hierarchical* simply means that smaller FSM’s can be recursively encapsulated as a state of a bigger FSM.

A dynamic event generation system triggers transitions between states. Complex actions can be described by using a scripting language to define them. In a word, the HFSM’s should be considered as the brains of the agents.

2.3 NAVIGATION

The virtual environments for the agents are based on 3D Euclidean geometry. A graphics engine handles this layer of the simulation, whereas the AI engine extracts information from the environment and feeds it to the agent (such as *there is an obstacle ahead*).

For the agents to achieve their goals, three aspects must be considered:

The sensor system: only the sight has been included in this version, modelled as an angular sector defined by the angle of vision and the visual reach (both parameters can be individually modified for each agent). Other important senses such as hearing are to be added.

The pathfinding algorithms: *Pathfinding* (one word) is an AI technique consisting of finding possible routes between two given points. Its implementation is based on the well-known A* algorithm (pronounced *A-star*).

Free navigation and obstacle detection: the problem with the pathfinding algorithm is that it computes a route which is not sensible to changes in the environment. To solve this, pathfinding is used along with free navigation algorithms which allow agents to avoid sudden obstacles returning afterwards to the nearest point in their pathfinding route.

3. RESULTS

The Colosseum model was originally provided by the Cultural Virtual Reality Lab, and was subsequently modified by the Light Simulation Lab to adapt it to the needs of the simulation (adding a few missing passages or simplifying the mesh when it was too detailed for the purposes of the project). The behaviour of virtual agents has been modelled, by using a continuous perception-action scheme and Hierarchical Finite state Machines.

Several simulations have been already tested on a Dual P4 Xeon@2.8Ghz, 2 GB of RAM and a GeForce FX 6800 Pro graphics card. Given that the problem is roughly symmetrical in two axes, only a quarter of the problem has been considered, thus reducing its complexity. Boundary issues between the four quarters of the Colosseum have not been taken into account yet. A total of 3,516 people have been introduced in the first two stories of the building, guided by the AI algorithms and their simple goal: to enter by the right door and find their assigned seats. All of them succeeded in finding their way around the building and occupying their place, avoiding obstacles in a dynamic environment where the presence of other agents dynamically changes the environment. Figure 4 shows some frames of the rendered simulations.

4. CONCLUSIONS AND FUTURE WORK

The complexity of the full task is fairly daunting, both because of the sheer size of the Colosseum and the massive amount of agents to be simulated. The simulation is therefore memory-intensive, and advanced optimization strategies must be developed in order to be able to scale the problem to its full dimension. The obvious remaining task is therefore to achieve a complete simulation in the whole building with approximately 50,000 agents.

In order to detect bottlenecks, rendering 3D animations is not really necessary; virtual "people counters" will be placed at key spots of the Colosseum instead, and measures of people flux will be visualized in false colour maps. This way, it will be easy to identify the suspected bottlenecks just by looking at high-stress areas in the map. Animations can be rendered *a posteriori* from a selected point of view once the interesting area of conflict is known.

Finally, different hypothesis will be tested: given that the shows lasted the whole day, it is doubtful that all the people would try to enter the building at roughly the same time, and most likely the building would only be at its full capacity during selected fights. Several timings for entering the building will therefore be tested and conclusions drawn. On the other hand, it is likely that, in whatever order spectators entered the building, the great majority left immediately upon the end of the last event. We will therefore also test the problems that occur when people left their seats and exited the amphitheatre.

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FIGURES

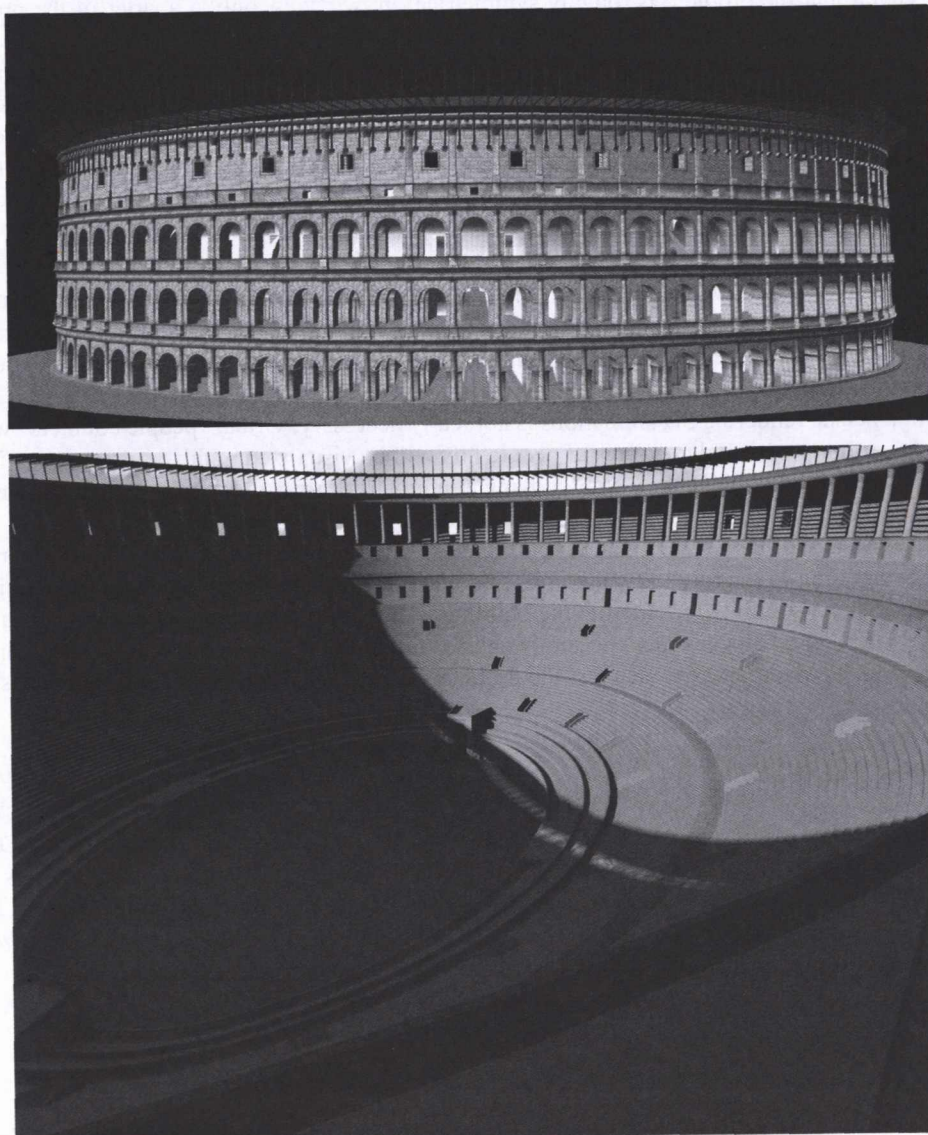


Fig. 1 – Model of the Colosseum, by the Cultural Virtual Reality Laboratory.

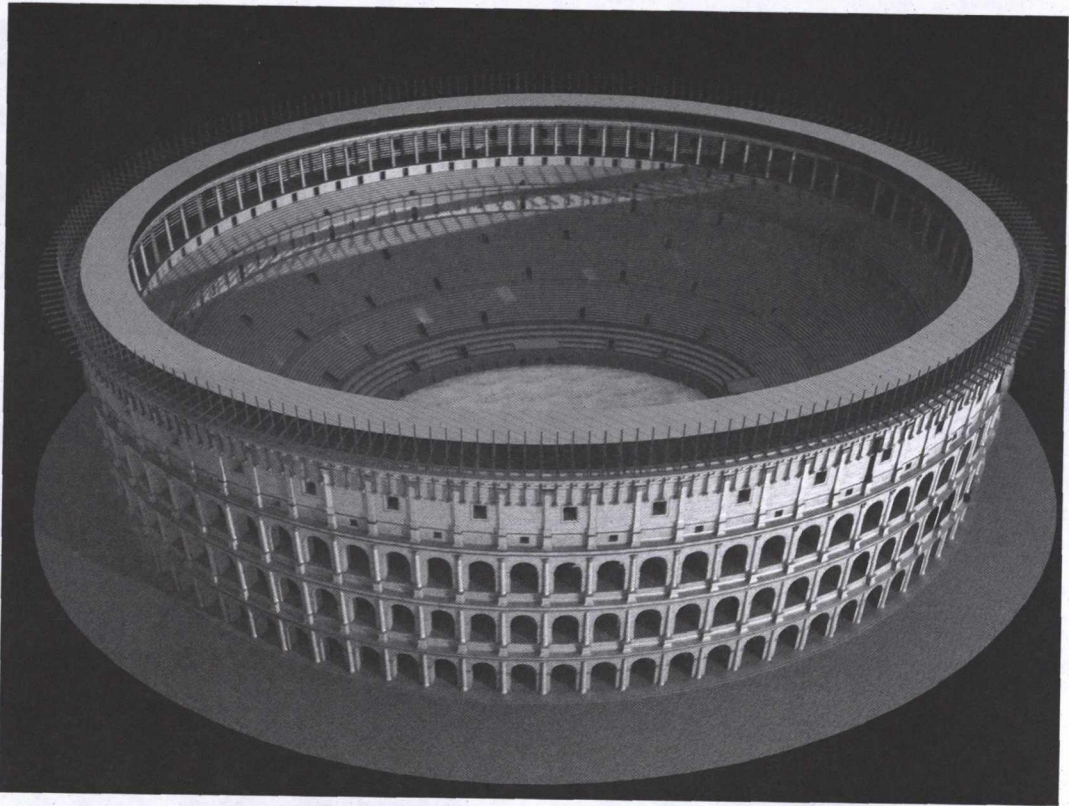


Fig. 2 – Model of the Colosseum, by the Cultural Virtual Reality Laboratory. Lit and rendered by the Light Simulation Lab

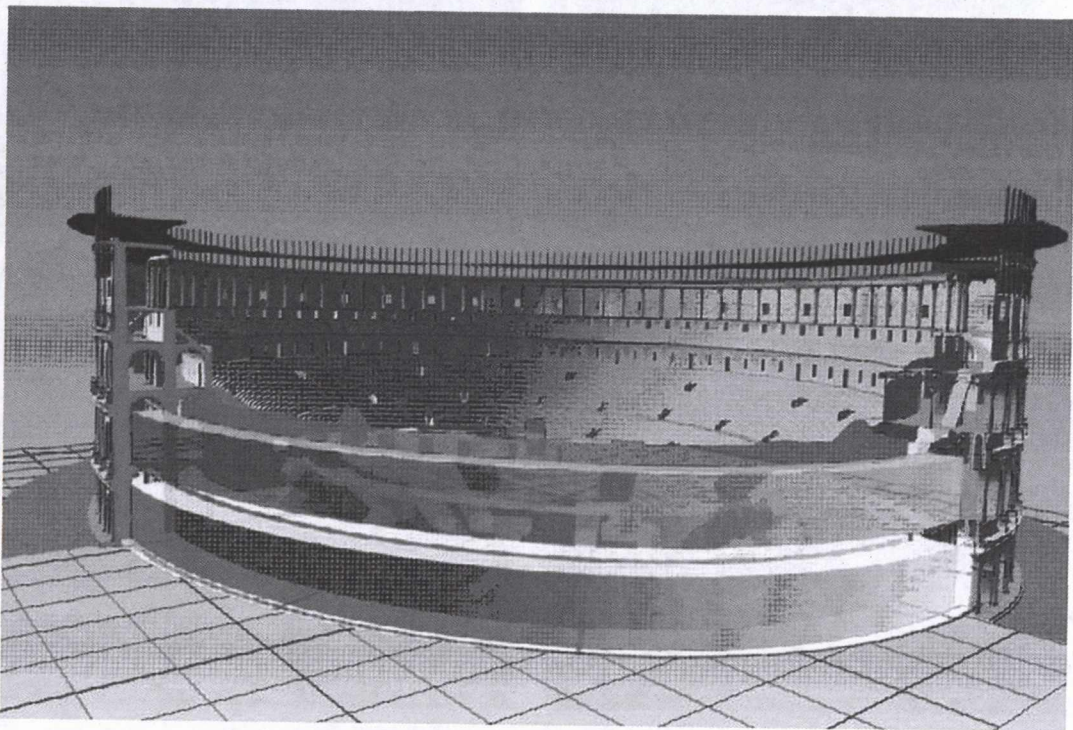


Fig. 3 – Routes through the Colosseum.

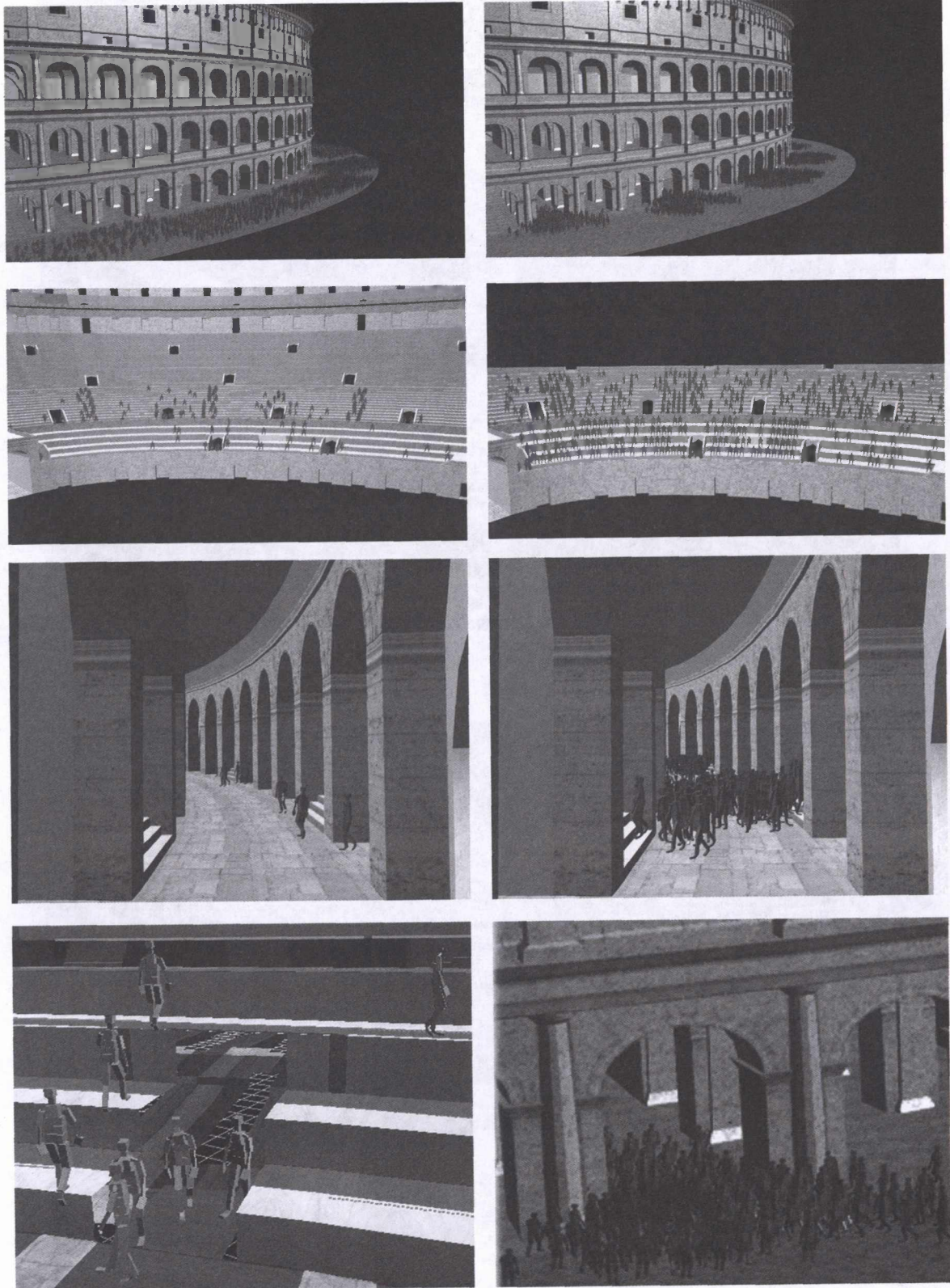


Fig. 4 – Some frames of the rendered Artificial Intelligence simulations.