

Simulations in the Minetest video game (Luanti) for sustainable development themes

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Summary: Since 2016, IGN France has offered a web service that allows users to generate worlds in the format of the sandbox video games Minecraft or Minetest (now renamed Luanti), which contain geographical data (relief, land use, hydrography, roads, buildings, etc.) on any location in France and around the world. With these playable worlds describing the territory of an existing location, the IGN has added functions to Minetest that enable simulations of physical phenomena to be carried out, to raise awareness of sustainable development issues. This article presents two types of simulation tool (flooding and photovoltaic energy) and compares the results obtained with real phenomena observed in reality

Keywords: video games, Minecraft®, Minetest, sustainable development, education, simulations, floods, photovoltaic energy.

1. Introduction

Over the last twenty years or so, education for sustainable development has been introduced into the various cycles of French school education. Its aim is to provide a complex understanding of the contemporary world, taking into account the interactions between the environment, society, the economy and culture. Various teaching themes have been identified¹ such as water and climate change (theme 3), sustainable management of natural resources (theme 4) and sustainable regional development (theme 5).

In order to tackle these subjects at different levels of schooling, this article proposes scenarios that can be used in an appropriate way within the framework of four cycles of French education (cycles 2 to 4 and lycée) and based on a tool appreciated by children of different school ages: the video game. The video game will be used to create educational simulations on two subjects: the flood risk and renewable energy.

1.1 Sandbox video games

Minecraft is the best-known and best-selling video game in the world. Comparable to a digital Lego®, it lets you wander in 3D through open worlds, where you can build (and destroy) imaginary worlds or represent places, alone or with others, using cubes. A free version exists, originally called Minetest, which became Luanti in 2024, offering the possibility of easily adding functions using the LUA language.

1.2 Minecraft/ Minetest on Demand service

In 2016, the Institut National de l'Information Géographique et Forestière (IGN France) set up a web service enabling users to order and receive Minecraft and Minetest worlds throughout France and the rest of the world, with geographical data describing the territory integrated into the game (Figure 1). Instead of playing in totally imaginary worlds, as these video games offer by default, the free online services Minecraft® on Demand and Minetest on Demand will enable you to find the relief, land use, hydrography, roads, buildings, etc. contained in the geographical databases in the 3D game. These elements will be represented using metric cubes (1 cube for 1 m³ on the ground), over a geographical area ranging from 500 m by 500 m to 5 km by 5 km, Lecordix *et al.*, (2019).

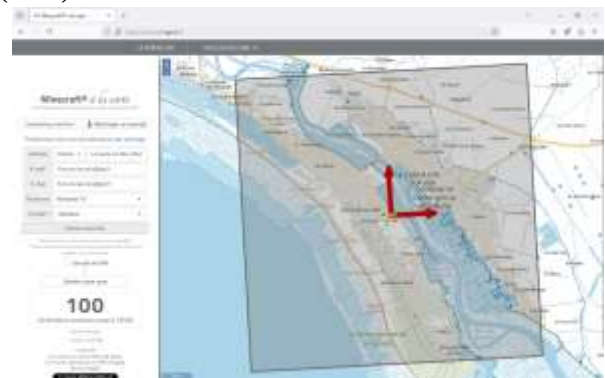


Figure 1. Minecraft® on Demand interface for selecting a 5km by 5km right-of-way at La Faute sur Mer.

¹ <https://eduscol.education.fr/3921/l-education-au-developpement-durable-dans-le-cadre-des-enseignements>

1.3 Characteristics of the worlds obtained

In France, by choosing to use the WMS and WFS flows for distributing geographical data, the worlds produced on demand by the Minecraft® and Minetest on Demand services will constantly be based on the latest data updated and distributed by the IGN. This is an important point to note for the flood risk simulations discussed in the next chapter. These services for delivering playable worlds have also been extended:

- to the Walloon region, in partnership with the Walloon Public Service (SPW), in this case exploiting an annual delivery of geographical data that will be used to calculate a world on an extract;
- to the whole world, with NASA SRTM data for relief, at a resolution of around 90 m, streamed and OSM vector data for topographic data, also streamed.

Options in this service also make it possible to have snow cubes deposited in varying thicknesses over the entire generated world.

The worlds produced in this way provide players with a simplified digital twin of a limited area of a territory of their choice, where they can find their bearings in 3D space in relation to reality and modify it as they wish using the basic cube construction and destruction functions included in the game.

It should be noted that the data in the game is georeferenced in three dimensions. In addition, the resolution can be configured in the service, between actual values of 1.0 to 2.0 cubes per meter.

For building facades, in the absence of descriptive data in the geographic data used, the decision was made to initially use solid colors (as is done, for example, in the IGN's Géoportail when displaying buildings in 3D), and then later to add symbolic textures of glass cubes surrounded by cubes representing construction elements (concrete, wood, etc.) on each floor to achieve a more realistic look.

To take realism even further, many users of their 3D map will interactively improve the rendering by using facade visualization tools such as StreetView or more specialized solutions, as illustrated in Figure 2 on Vandoeuvre-lès-Nancy², created in Minecraft by YouTuber Elysium Fire for the city³.



Figure 2. Improved rendering of the town of Vandoeuvre-lès-Nancy in Minecraft® (top), by YouTuber Elysium Fire, based on the map provided by the Minecraft® on Demand service and using 360° views published by the town and produced by Unitorial (bottom).

1.4 Educational tools

Many teachers have used the Minecraft or Minetest games and the service offered by IGN to generate playable worlds. Two examples can be cited:

- The Dijon and Limoges academies have launched the Minestory project, which *aims to enable pupils to virtually explore the sites modelled in the Minetest game, but also to help them become mediators of their discoveries by producing documents explaining the history and architecture of each site*⁴.
- Thanks to this simplified representation of the area and these basic functions, the Institut de Recherche et d'Innovation (IRI) has undertaken, from 2020 to 2024, the UNEJ (Urbanités Numériques En Jeux) educational project of citizen consultation in the schools of the Département Seine-Saint-Denis, to make proposals for the development of their school, their neighbourhood and then the site of the Olympic Village after the 2024 Olympic and Paralympic Games⁵.

² <https://vandoeuvre.unitorial.com/visite-2-la-ville/2>

³ <https://www.villes-internet.net/actions/655b128f7da105706548a328>

⁴ <https://minetest.wp.ac-dijon.fr/minestory-frise-immersive-de-sites-du-patrimoine-architectural/>

⁵ <https://tac93.fr/fr/activities/unej/>

This work is often used to address teaching theme 5: sustainable regional development.

Before addressing this topic, it is important to emphasise that, compared to other 2D or 3D educational GIS (Arcgis, Cesium, etc.) with more features, using gaming software that all students already know how to use—sometimes better than their teachers—means you don't waste time teaching them how to use the tools and can focus solely on the topic you want to cover.

In addition, because they can be played online and allow several players to work together on the same map (each student can see the avatars of the other students participating in the map), Minecraft® and Minetest offer additional opportunities for collaborative work, rather than the individual work that is usually done in educational GIS

2. Flood simulations

2.1 Added tools

To go beyond the basic construction tools available in Minetest, the IGN has proposed, as part of the Innovative Pedagogical Tools in the Minetest Universe project, funded by the French Ministry of Education via the Plan d'Investissement d'Avenir programme, to introduce new tools for simulating natural hazards (floods, avalanches, mudslides, volcanic eruptions, hurricanes) described by Lecordix and Kumarasamy (2021).

For floods, part of theme 3 of the teaching, the first tool developed in the game and its 3D visualisation allows the water to rise by a metric value (integer value of cubes) from a block of water present in the game (river, lake, sea, etc.) and selected by the user. Thanks to the representation of the relief present in the Minetest world, the water will then extend to all the cubes located above the ground, up to the height chosen by the user, and in direct proximity to the selected water cube (or voxel) and its neighbouring cubes. This very simplistic hydraulic modelling can only be used for slow flooding of lowland rivers. The user can then move around the Minetest game to view the flooded areas in 3D.

The second tool added to the game allows you to switch to a browser to view the extent of the flood simulation in 2D, based on the selected water level. This view can be transparent with the topographic map or the orthophoto of the game area. Each time the height of water experienced is modified, the mapping of the extent of the flooding in the game will be updated in the browser.

2.2 Flood experiments already carried out

2.2.1 Hundred-year flood of Paris 1910

In order to test the educational value of these simulations, an initial experiment was carried out during the project on the 1910-hundred-year flood of the Seine and Marne rivers in the Paris region. An area upstream of Paris, at Le Perreux sur Marne, was chosen and the Minetest world was generated by the Minetest on Demand service, using geographical data that existed a century later. By varying the height of water in the game, and then producing 2D maps of the simulated flooding in the chosen area, a

comparison was made with the historical 2D maps of the 1910 flood, available online on the IGN Géoportail website. This experiment showed (Figure 3) that the extent of the flooding was very similar between the 2 maps, validating the value of the tools for teaching and raising awareness of the problem of slow-onset flooding.

2.2.2 Couthures sur Garonne flood of 2021

The same exercise was repeated for a more recent flooding event on the Garonne in February 2021, which was followed by the daily news, particularly at Couthures sur Garonne, which was the subject of numerous newspaper reports and photos (Figure 4).



Figure 3. Comparison between the simulation obtained with the 2D tools associated with Minetest (top) and the historical 2D maps of the 1910 flood, available online on the IGN Géoportail website, at Le Perreux sur Marne (bottom).

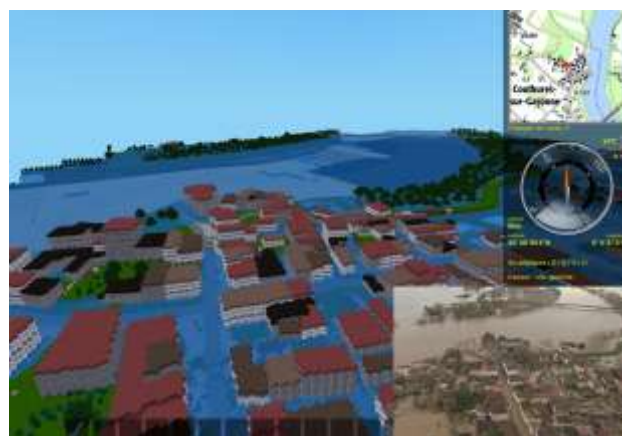


Figure 4. Comparison between the Minetest 3D simulation and an aerial photograph of a flood at Couthures sur Garonne in February 2021.

2.3.3 Limitations of the experimental data

Before launching the simulations, it's worth remembering that they will be carried out using geographical data released in 2024 by the IGN and used in the Minecraft on Demand service. Since the disaster, a number of major improvements have been made and houses destroyed to prevent a recurrence. Figure 8, taken from the Remonter le temps service, shows the differences between 2005 and 2021, particularly in terms of housing.



Figure 8. Visualisation of habitat changes between 2005 and 2021 at La Faute sur Mer.

2.3.4 Marine submersion simulation

Devaux *et al.* (2012) recall the usual causes of water ingress during marine submersions (Figure 9):

- overflow: when the sea level is higher than the structure or the natural terrain, the water overflows and floods the land behind it;
- sea surge crossing: waves breaking against a structure allow water to pass over it;
- the formation of breaches: the rupture of a natural (dune belt) or artificial protection allows water to enter the areas behind it.

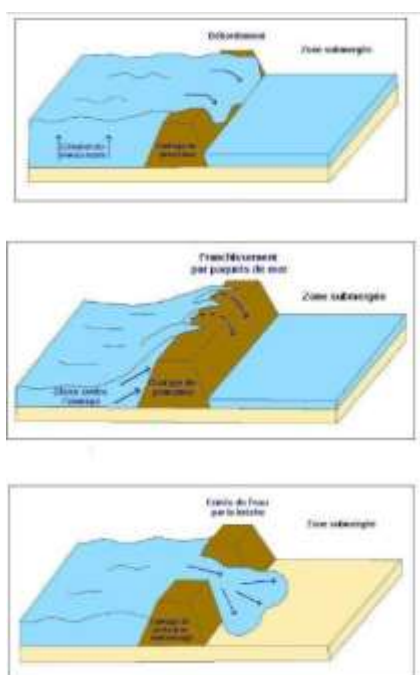


Figure 9. The three causes of flooding (Devaux *et al.* 2012)

Once you have ordered and loaded the world of La Faute sur Mer from Minetest on Demand service, you can get started with the educational simulations in the game.

2.3.5 Overflow simulation

This scenario is very similar to the two simulations presented above for the Marne and Garonne rivers, with a rise in water levels using the tool developed in Minetest, followed by 2D mapping to visualise the result shown in Figure 10.



Figure 10. Overflow simulation in Minetest

The result of this simulation bears little resemblance to the map shown in Figure 6. It should also be noted that this scenario is undoubtedly closer to the one envisaged in the years to come with climate change and the general rise in sea levels over the next few decades

2.3.6 Sea surge crossing simulation

This scenario does not appear to be easily achievable using the tools currently available. However, it should be fairly close to the previous simulation.

2.3.7 Breaches simulation

In the basic Minecraft and Minetest games, water cubes have a behaviour (called mod) that allows them to propagate into nearby air cubes at the same height or below and then flow onto lower surfaces.

Based on the location of the breach points mapped in Figure 7 and using the basic functions of these sets to break a few cubes of the dyke, a flow of cubes of sea water will occur on the Minetest map. The operation is repeated at the three breaches shown in Figure 11.



Figure 11. Location of a breach where dyke cubes will be destroyed to cause the water to flow.

Once the flow through the three breaches shown in Figure 7 has been completed, the results can be viewed locally in 3D and a complete 2D map of the flooding in the commune of La Faute sur Mer can also be produced (Figure 12).

It should be remembered, however, that as the map generated in Minetest is based on topographical data from 2024, many houses that were there before storm Xynthia have since been destroyed, particularly in places where flooding is clearly visible in the simulation (the central and northern breaches). Conversely, on the northernmost breach, the simulation does not show any flooding in the rectangular area protruding from the sea: development work has since been undertaken to protect or raise this area.



Figure 12. Minetest simulation overtopping in three breaches at La Faute sur Mer, with red dashed line superimposed on the mapping observed by SERTIT during storm Xynthia.

2.3.8 Summary of flood simulations

Similarities can be seen between the simulation obtained and the cartography produced by the SIRTIT during the crisis, even if the resolution used in the game (1 cube for 1 m³) probably does not allow a more accurate approximation of the result observed in the field. It is, however, sufficient to meet the educational needs of pupils, who can thus grasp the issues, understand the situation, experiment with solutions and discuss how to adapt.

3. Photovoltaic simulations

3.1 Principle of photovoltaic energy

In order to tackle another sustainable development theme in education, theme 4 on the sustainable management of natural resources, the subject of photovoltaics was chosen, again using the Minetest game and the simulations on a territory made possible by the Minecraft® on Demand service.

The photovoltaic effect is the ability of certain materials to convert light into electricity. It is a physical phenomenon in which a material emits electrons under the effect of light, making it possible to produce sustainable electricity.

The installation of photovoltaic panels is now accessible to everyone, and over the last few years the government has made a number of efforts to encourage people to install photovoltaic panels, in particular by producing and distributing communal rooftop solar maps.

3.2 Solar cadastres and parameters for calculating photovoltaic energy

The aim of a rooftop solar register is to identify the locations with the best exposure to solar radiation on rooftops in a given area, and to provide simulation-based estimates of the theoretical amount of electricity that can be generated per m² per year.

First introduced in France in the early 2010s, the solar cadastre can be calculated with varying degrees of precision depending on the parameters taken into account. Three types of parameters can be identified for calculating the photovoltaic quantity produced by a solar panel on a given point on the roof, apart from the panel's own physical characteristics:

- Global solar irradiation, which measures the amount of solar energy received per unit area per year. This will depend on the location (in longitude and latitude) in the area and the meteorology of the site recorded over many years.
- The positioning of the solar panel, which generally follows the shape of the roof in terms of orientation and inclination to the sun.
- Shading, which modifies the amount of sunlight very locally, either through close shading (trees, other houses, chimneys, etc.) or distant shading linked to the relief (mountains).

3.3 Introduction to the Minetest game

Based on this technical knowledge, an experiment was carried out to introduce the possibility of adding solar panels to the Minetest game and then, for educational purposes, estimating the amount of photovoltaic energy produced.

Note that in the maps produced by the Minetest on Demand service, the cartographic coordinates of the ordered map are stored as metadata, so that for any block on the Minetest map, it is possible to know the cartographic coordinates of the location. This information is essential if the solar irradiation at a point on the Minetest map is to be taken into account.

However, for simplicity's sake, the influences of shading are not taken into account in the calculation.

3.3.1 Creation of directional solar panels

The first step was to add a Minetest block representing a solar panel. After a few tests, a 3D object of a solar panel was built in Blender. In order to display different tilt possibilities, different block models were integrated with 4 possible tilts (0°, 30°, 60°, 90°) which are presented in Figure 13.

All the functions associated with the solar panels have been entirely coded in LUA. With these developments, the solar panel (based on a cube) can rotate according to the

four cardinal points (North, East, South and West) simply by rotating the base block by 90°. To switch between the 4 inclinations indicated above, four separate blocks have been combined to give the illusion that the same block has several inclinations.

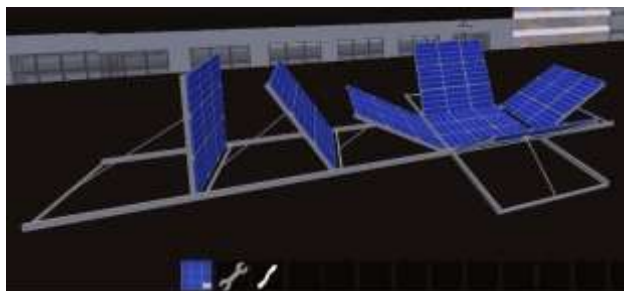


Figure 13. Orientation (North, South, East, West) and tilt (0°, 30°, 60° and 90°) of the solar panels created in the Minetest game, with the 3 buttons at the bottom to manipulate them: Create-Destroy, Orientation-Tilt, Select-Calculate.

An additional parameter has been added: luminosity. Calculating the photovoltaic energy of a solar panel is only realistic if there is sufficient ambient light, i.e. if the block is not inside a building. Each block has a specific brightness level, which can be retrieved using Minetest's "get_node_light" function. This value varies from 0 to 15, where 0 corresponds to a total absence of luminosity and 15 indicates maximum luminosity. This means that the solar panel is inactive below a certain brightness threshold. Functions have been added to enable the parameters relating to the solar panel (luminosity, coordinates, orientation and inclination) to be retrieved at any time, so that this information can be used and displayed to deduce the photovoltaic potential.

A solar panel can be selected and deselected at any time to change its characteristics.

3.3.2 Calculation of photovoltaic potential in the game

The photovoltaic potential can then be calculated for one or more selected solar panels.

To calculate the energy produced by a panel, we need to collect the inclination, orientation and region in which the map is located. Once all this data has been retrieved, we use the Calsol software⁶ offered for educational purposes by the Institut National pour l'Energie Solaire (INES), to calculate global solar irradiation (GSI)⁷.

"Global Irradiance in the IGP plane: is the actual luminous energy received from the sun at the earth's surface whose inclination and orientation have been defined. This value is the sum of Direct Irradiation in the IBP plane, Diffuse Solar Irradiation in the IDP plane and Reflected Solar Irradiation in the IRP plane".

We stored the IGP values as a function of inclination and orientation in a dedicated table in our database. The result is in kiloWatt-hours per square metre. As the IGP is in KWh/m², it must be converted into equivalent hours (number of hours of sunshine). The energy (E) produced is equal to the power (P) multiplied by the time (t) during which the power is applied. The time is represented by the

number of hours of sunshine, the IGP converted into hours. This result is multiplied by the installed peak power (Pc). For the peak power, we take the base power set at 340 W, i.e. 0.34 kW for a standard solar panel with 60 cells measuring 1.7 m². The overall solar irradiation (in equivalent hours) is multiplied by the installed peak power and by 0.75, because the Calsol software uses a PV module electrical conversion efficiency of 75%. This gives the annual production in kWh:

$$E = P \times t = P_c \times 0,75 \times IGP$$

The use of professional solar cadastres distributed in certain communes, which give photovoltaic production at 1m intervals, will make it possible to validate the calculations presented above and displayed in the game, provided that the buildings chosen are not affected by far or near shading.

3.3.3 Setting up benchmarking tools

The value of photovoltaic production displayed is not a very meaningful value for children, or even for adults who are not professionals in the field. That's why we've added elements for comparison with the consumption of everyday objects such as cars, televisions, telephones and tablets. So, with the panels selected in the game (Figure 14), the user will be able to associate the number of kilometres travelled in the car or the time spent using energy-consuming objects, etc. with the consumption of energy.



Figure 14. Calculation of the photovoltaic energy produced per day by five of the panels placed and selected in the game, and comparison with the number of kilometres achievable with a car.

3.4 Experimenting with children

All the tools presented above are often presented in schools and taken up by certain teachers who adapt them to their teaching needs. In the extra-curricular context, the IGN supported an experiment with a sports association, the Saint-Mandé Football Club, which wanted to run an innovative daily event on the theme of renewable energy. Over the course of 5 days and 1 hour of activities, around twenty children divided into groups of 3 were each able to propose a scenario for adding a grandstand to their stadium, with solar panels on the roof, and present their results to their parents and the town council (Figure 15).

⁶ <http://ines.solaire.free.fr/>

⁷ <http://ines.solaire.free.fr/pages/expppvresau1.htm>

The event was awarded the Trophées Philippe Séguin 2024⁸.



Figure 15. Renewable energy activity at FC Saint-Mandé using the Minetest game with photovoltaic panels.

4. Conclusion and outlook

The concept of the Digital Twin consists of a digital reproduction of a real object, with the aim of meeting a need that includes visualisation and/or simulation. In the field of geographic sciences, the object of interest is the territory. Based on this principle, we can consider the Minecraft/Minetest on Demand service as a tool for creating digital twins.

The basic service provides a 3D representation of the area, integrated into a fun, adaptable environment. The simulation functionalities that can be integrated afterwards enable users to respond to more targeted needs, such as sustainable development issues.

We might then ask ourselves whether Minetest, which originated in the gaming world, meets all the criteria of a 3D GIS: it allows users to collect, store, process, analyse, manage and visualise spatial and geographical data.

However, there are certain limitations with the current tool. Indeed, by its very nature, it is designed to work with cubic environments, which limits certain types of processing and impacts the accuracy of the results that can be obtained with reasonable computing resources. It also works in a similar way to an export, and currently retains little or no link with the source data. This has an impact on 'return' capabilities for actions carried out in an exported world.

However, it also lays a solid foundation for the design of a more advanced tool for creating digital twins, and offers an outline of a method for integrating modules - particularly simulation modules - to meet requirements. It also supports the idea that a tool and environment specific to the need (for example, Minetest for education) is beneficial. Work can be carried out using this tool to extend its principles to an elementary digital twin.

5. Reference

Chauveau, E., Chadenas, C., Comentale, B., Pottier, P., Blanlœil, A., Feuillet, T., Mercier, D., Pourinet, L., Rollo, N., Tillier, I. and Trouillet, B. Xynthia: lessons

from a disaster In: *Cybergeo*, n°538, 2011 <https://doi.org/10.4000/cybergeo.23763>

Devaux, E., Desire, G., Boura, C., Lowenbruck, J., Berenger, N., Rouxel, N., et Romain, N. *La Tempête Xynthia du 28 février 2010, Retour d'expérience en Loire-Atlantique et en Vendée*. Direction régionale de l'environnement, de l'aménagement et du logement Pays de la Loire, 2012. https://www.pays-de-la-loire.developpement-durable.gouv.fr/IMG/pdf/rapport_REX_final.pdf

Lecordix, F., Kumarasamy, S., Da Graca, F. and Kriat, S. Preparation of the Future with Minecraft® on Demand. In: *Proc. of the International Cartographic Association*, 2, 2019, 29th Cartographic Conference, 15-20 July 2019, Tokyo, Japan. <https://ica-proc.copernicus.org/articles/2/72/2019/ica-proc-2-72-2019.pdf>

Lecordix, F. and Kumarasamy, S. Teaching on natural risks by simulation in Minetest and augmented reality. In: *Abstracts of the International Cartographic Association*, 3, 2021. 30th International Cartographic Conference, 14-18 December 2021, Florence, Italy. <https://ica-abs.copernicus.org/articles/3/173/2021/ica-abs-3-173-2021.pdf>

⁸ <https://www.fff.fr/article/14561-fc-saint-mande-du-jeu-a-l-energie-renouvelee.html>