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A MECHANISM TO AUDIT 3D GEOMETRIES SUBMITTED FOR PRINTING IN A 3D PRINTER

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A Mechanism to Audit 3D Geometries Submitted for Printing in a 3D Printer

This disclosure proposes a mechanism for auditing the content being printed in a 3D printer. It is based in a digital signature so that some user with appropriate privileges is able to digitally sign the parts validated by himself. This validation can be done both in the pre-print Software application or in the printer Control Panel. Then, the printer validates that all the parts conforming the job have been validated by checking that the contain the appropriate digital signature. All the validations are stored in an internal database using an audit trail mechanism.

When going from prototyping to manufacturing one of the identified gaps for 3D printing has been the availability of tracking audit trails of relevant events. A potential application of audit trails can be to keep a proof of evidence of the different operations by different users over the 3D printing of a digital model/part. This is usually a requirement under very regulated environments such as medical or aviation applications. One of the key topics to keep track of is the content being printed. In some application it may be wanted that some supervisor approves the printing of selected digital models. Other use cases may be to prevent the printing of not-allowed models, such as weapons in countries where this is prohibited, or models which may be protected by Intellectual Property. To be able to expand 3D printing to environmenst with such requirements, we propose a method to allow the printer to guarantee that all the printed content is audited by some authorized person. Our method allows performing the auditing either from the pre-print SW application (or both), taking advantage of 3MF Digital Signature capabilities, or in the printer itself in the cases where the printer's Front Panel allows a visual inspection of the 3D models to be printed.

Audit trails or audit logs is a well-known mechanism to "*generate a security relevant record set of records, and/or destination and source of records that provide documentary evidence of a sequence of activities that have affected at any time a specific operation, procedure or event*". Certain regulated environments have requirements of having audited operations done. To be able to expand 3D printers to these new applications having these requirements, we propose the following method. The method defines a two-step workflow (*Figure 1*): In the first step, we give the user to approve the printing of one or more parts in a job from the pre-print SW application. This step is optional; In the second step, the printer validates that all the parts have been approved for printing before allowing the printing to start. If this is not the case, it will block the printing till an authorized user approves the printing of the parts. Then, the 3D printer keeps track of the user which validated the content, either in the first or second step, and allow the printing to start.

Figure 1. Standard workflow for models/jobs with digital signatures.

Auditing content in pre-print SW application

When an operator collects parts to be printed and composes a job fitting the parts in the printable area of the printer, then a supervisor can validate the content which will be submitted to the printer. At this point, he can visually inspect every part and validate its printing by digitally signing it. Also, there would be the option to digital sign a whole job. To digital sign the part, the computer hosting the pre-print SW application has to have a Digital Certificate which will be used. When the supervisor validates a part or a job, he will have to insert a user and password associated to the Digital Certificate. Then, when the job is submitted to the printer, the digitally signed parts will include a Digital Certificate as supported by OPC, which is the standard in which is based 3MF [3]. To be able to support the Digital Signature per part, every part has to be encoded in a different XML, using the *path* attribute from the 3MF production extension (which is a required extension).

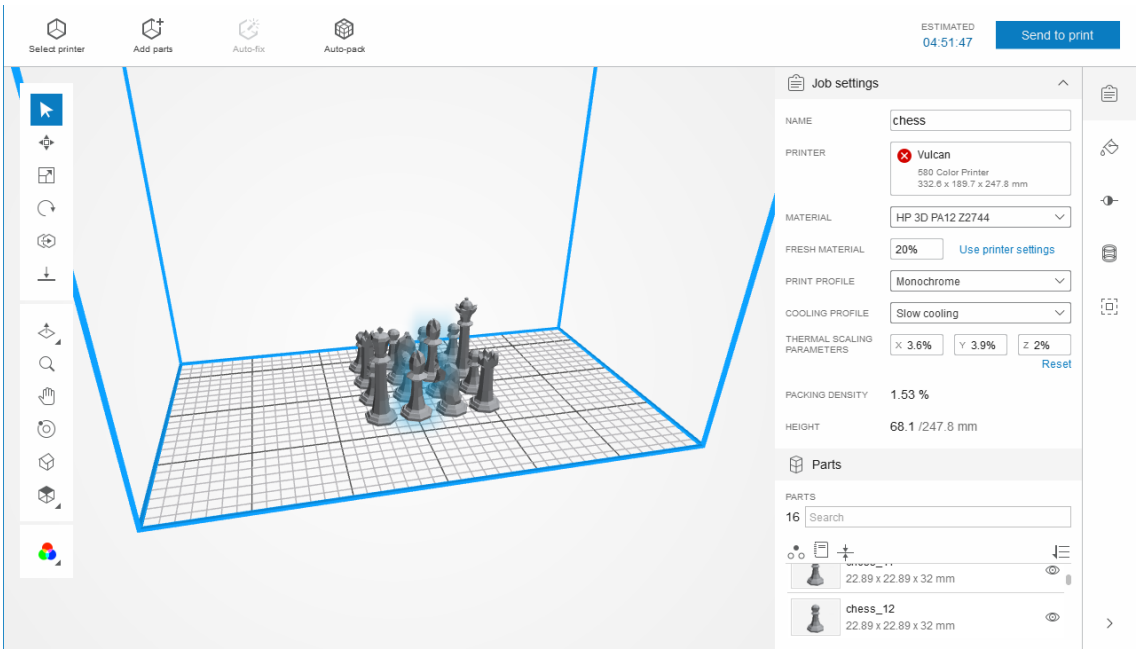

Figure 2. Example of a print job containing 16 parts representing the chess pieces

For example, in the case of job from *Figure 2*, where we have 16 parts representing the chess pieces, let's suppose that supervisor chooses to approve the two bishops for printing. For that purpose, he should select each of them and select to Digitally Sign the parts. When generating the 3MF to be submitted to the printer, the pre-print SW will encode the parts in separated files using the path attribute as shown in *Figure 3*.

```
<?xml version="1.0" encoding="utf-8"?>
<model xmlns="http://schemas.microsoft.com/3dmanufacturing/core/2015/02" unit="millimeter" xml:lang="en-U
"http://schemas.autodesk.com/dmg/loadcase/2016/08" xmlns:t="http://schemas.autodesk.com/dmg/tetrahedron/2
"http://schemas.microsoft.com/3dmanufacturing/slice/2015/07">
    <resources>
    </resources>
    <build p:UUID="800e5984-a9d9-4ade-93e0-3526b35fe42e">
        <item objectid="1"  p:UUID="f684a22a-64c2-493f-9e4b-f756ca69175e" p:path="/3D/ches_2.model" />
        <item objectid="2"  p:UUID="dd3bc68a-fdc4-4d40-a6a6-f0a64bc9dbe0" p:path="/3D/ches_3.model" />
        <item objectid="3"  p:UUID="a27d5cc8-a351-4a1e-941a-3c75515b8a49" p:path="/3D/ches_4.model" />
        <item objectid="4"  p:UUID="1d64a142-2e5f-477d-b609-962969b8b3cf" p:path="/3D/ches_5.model" />
        <item objectid="5"  p:UUID="d8e6a77a-50a2-481b-bbe8-8eb216b2f6b9" p:path="/3D/ches_6.model" />
        <item objectid="6"  p:UUID="ae6391a1-13a4-4ebd-8e37-9e0d5a65f174" p:path="/3D/ches_7.model" />
        <item objectid="7"  p:UUID="0b4950b2-3fbe-4227-90f8-185441cf81af" p:path="/3D/ches_8.model" />
        <item objectid="8"  p:UUID="72e9659c-5eb1-468a-8b76-dc76806c8e09" p:path="/3D/ches_9.model" />
        <item objectid="9"  p:UUID="c3b5c07d-3a87-46ff-be27-71b9c611bd1b" p:path="/3D/ches_10.model" />
        <item objectid="10" p:UUID="1c5707a8-d07a-4fe9-bfb3-a8101fa53649" p:path="/3D/ches_11.model" />
        <item objectid="11" p:UUID="a0d7c4d6-28be-431f-aa6e-4d7b9ac3b7db" p:path="/3D/ches_12.model" />
        <item objectid="12" p:UUID="43a87057-8857-4bd8-8ecc-602bb8314e8a" p:path="/3D/ches_13.model" />
        <item objectid="13" p:UUID="948e91ac-c2d8-4dd1-9de9-54c38a172232" p:path="/3D/ches_14.model" />
        <item objectid="14" p:UUID="36100b7b-fcd6-4323-82e7-ec71942deadf" p:path="/3D/ches_15.model" />
        <item objectid="15" p:UUID="b3abe967-9253-4023-b964-6572e9ad5a83" p:path="/3D/ches_16.model" />
        <item objectid="16" p:UUID="083eded3-16d4-4af1-8159-750ff982d1dd" p:path="/3D/ches_17.model" />
    </build>
</model>
```

Figure 3. Example of the generated 3MF encoding every part in a different 3MF model file

Then, the relationships for the main 3MF model file should define the relationship from the main model to the parts models as shown in *Figure 4*.

```
<?xml version="1.0" encoding="UTF-8" standalone="no"?>
<Relationships xmlns="http://schemas.openxmlformats.org/package/2006/relationships">
    <Relationship Id="rel1" Target="/3D/ches_2.model" Type="http://schemas.microsoft.com/3dmanufacturing/2013/01/3dmodel"/>
    <Relationship Id="rel2" Target="/3D/ches_3.model" Type="http://schemas.microsoft.com/3dmanufacturing/2013/01/3dmodel"/>
    <Relationship Id="rel3" Target="/3D/ches_4.model" Type="http://schemas.microsoft.com/3dmanufacturing/2013/01/3dmodel"/>
    <Relationship Id="rel4" Target="/3D/ches_5.model" Type="http://schemas.microsoft.com/3dmanufacturing/2013/01/3dmodel"/>
    <Relationship Id="rel5" Target="/3D/ches_6.model" Type="http://schemas.microsoft.com/3dmanufacturing/2013/01/3dmodel"/>
    <Relationship Id="rel6" Target="/3D/ches_7.model" Type="http://schemas.microsoft.com/3dmanufacturing/2013/01/3dmodel"/>
    <Relationship Id="rel7" Target="/3D/ches_8.model" Type="http://schemas.microsoft.com/3dmanufacturing/2013/01/3dmodel"/>
    <Relationship Id="rel8" Target="/3D/ches_9.model" Type="http://schemas.microsoft.com/3dmanufacturing/2013/01/3dmodel"/>
    <Relationship Id="rel9" Target="/3D/ches_10.model" Type="http://schemas.microsoft.com/3dmanufacturing/2013/01/3dmodel"/>
    <Relationship Id="rel10" Target="/3D/ches_11.model" Type="http://schemas.microsoft.com/3dmanufacturing/2013/01/3dmodel"/>
    <Relationship Id="rel11" Target="/3D/ches_12.model" Type="http://schemas.microsoft.com/3dmanufacturing/2013/01/3dmodel"/>
    <Relationship Id="rel12" Target="/3D/ches_13.model" Type="http://schemas.microsoft.com/3dmanufacturing/2013/01/3dmodel"/>
    <Relationship Id="rel13" Target="/3D/ches_14.model" Type="http://schemas.microsoft.com/3dmanufacturing/2013/01/3dmodel"/>
    <Relationship Id="rel14" Target="/3D/ches_15.model" Type="http://schemas.microsoft.com/3dmanufacturing/2013/01/3dmodel"/>
    <Relationship Id="rel15" Target="/3D/ches_16.model" Type="http://schemas.microsoft.com/3dmanufacturing/2013/01/3dmodel"/>
    <Relationship Id="rel16" Target="/3D/ches_17.model" Type="http://schemas.microsoft.com/3dmanufacturing/2013/01/3dmodel"/>
</Relationships>
```

Figure 4. Example of the relationships of the main 3MF model to the rest of part models.

The 3MF file should include a Digital Signature origin OPC-part acting as the root of the digital signature payload in the 3MF document. Then, the individual parts to be signed (the two bishop parts, named "chess_5" and "chess_8") include a Digital Signature which can be discovered from the Digital Signature Origin OPC-part. The OPC-part for the individual Digital Signatures can have either an inline digital certificate, or a reference to an external Digital Signature Certificate part in the package. The generated 3MF including Digital Signatures is then submitted to the printer.

Auditing content in the 3D printer

When the printer receives the 3MF it process the content as usual, and also validates the Digital Certificates included in the 3MF. Then marks the already validated parts as signed by the application with the corresponding Digital Certificate. Then, when the job is submitted to be printed, first of all the printer should check that all the parts have been validated. If that is the case, it will continue with

the printing. But if it is not the case, it will show a modal dialog stating that some parts require to be approved by a supervisor in order to be printed. The printer will show a mechanism to the supervisor for visually inspecting the content and digitally sign them for approval by providing a user and password. The printer will keep track of all these events by internally writing one or many audit trails into a secured database. The audit trails also will be generated for the parts which were digitally signed from the pre-print SW application. Finally, when all the parts are validated, the job printing will start.

The proposed method has the following advantages:

- It allows to expand 3D printers to regulated environment which may require of auditing of printed content.
- Allows that an authorized user is able to approve either a single part of a job or a whole job from the pre-print SW application.
- The authorized user is also able to approve the not previously approved parts from the printer itself by providing its user and password.
- The printer is capable of preventing content which has not been audited by an authorized user.

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